# Corrosion

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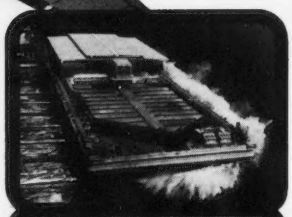
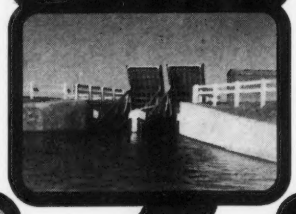
# The new corrosion film everyone is talking about!

Here is an authoritative film that answers many questions on the theory of corrosion and demonstrates methods by which it is controlled. Presented in color and sound, it ranges from the formation of anodes and cathodes through the use of galvanizing, inhibitors, metallizing, cathodic protection, alloys and protective coatings. You will see how many corrosion problems in industries such as yours are being solved by Dimetcote, a one-coat zinc silicate protective coating. This film will be well worth 19 minutes of your time. To arrange a showing for you and your associates, or to learn when it will be shown in your area, contact any of the Amercoat offices listed below.





**Typical audience reactions:**

Bishop, Tex.—"Planning fair-sized test after seeing this film."

Louisville, Ky.—"Answers many questions. Second showing arranged."

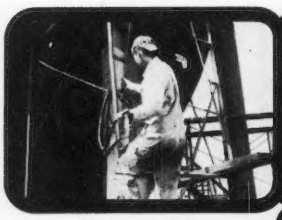
Cincinnati, Ohio—"Key personnel evidenced considerable interest."

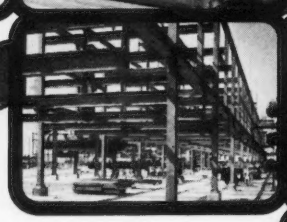
Netherlands Antilles—"Both shows led to 45-minute discussions."

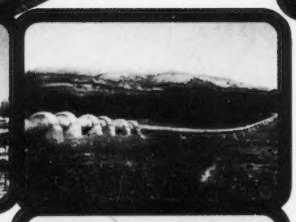
Fairport, Ohio—"Very interesting. Will try methods shown."

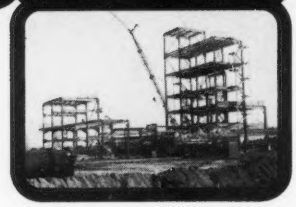
Las Piedras, Venezuela—"Putting ideas to work in near future."

Bartlesville, Okla.—"Viewed by 42 key men from five divisions."









**Answers these and other questions:**

What produces electrolytic corrosion?

What factors favor hot-dip galvanizing?

How important is surface preparation?

Can a coating survive a tank fire?

Can rust in tankers be controlled?

Can a coating offer cathodic protection?

What are the corrosion problems on offshore rigs?

What are the advantages of zinc silicate?

How can chemical plants cut painting costs?

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# ACP ALODINE* — its properties and functions in protecting aluminum alloys and bonding paint to them

By ALFRED DOUTY: Technical Director, AMCHEM PRODUCTS, INC.

Aluminum protects itself against corrosion by a coating of its own oxide. This adds weight, but does not provide complete protection. Even commercially pure aluminum in clean air at ordinary room temperature oxidizes indefinitely.

The use of adherent inorganic protective coatings on aluminum has long been recognized as efficacious in reducing corrosion rate and prolonging paint life. Since aluminum oxide tends to be protective, it is natural that the most intensive early efforts in this direction should have involved processes for improving the properties of the naturally occurring oxide coating. Anodizing, or electrochemical oxidation, although it is one of the most effective of such methods, is rather costly and time consuming.

## ALODINE†

Early in 1945 a new chemical process was devised for producing an amorphous phosphate coating on aluminum. Its simplicity, speed and economy and the unique properties of the coating have resulted in wide commercial acceptance. It is called the Alodine Process.

Some idea of the effectiveness of the Alodine coating on unpainted 3S Grade aluminum may be had from Fig. 1. All panels were removed from the salt spray cabinet after 300 hr. except the Alodized and anodized panels, which were continued to 800 hr.

Organic protective and decorative coatings, such as paint, likewise require a corrosion-retarding undercoating of the kind produced by Alodine to achieve their maximum life and adhesion.

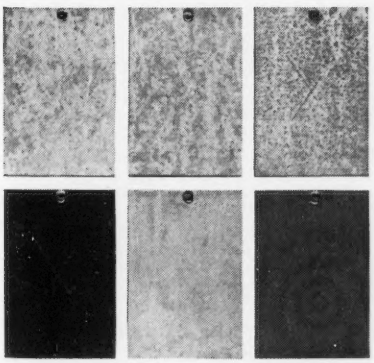

Fig. 1. Salt spray test comparison of Alodine with other surface treatments on unpainted aluminum. (Left to right, top row) solvent wiped —300 hr.; alkali cleaned—300 hr.; phosphate coated—300 hr. (Bottom row) chemically oxidized—300 hr.; anodically oxidized—800 hr.; Alodized—800 hr.

The effect of the Alodine coating in retarding underpaint corrosion is shown in Fig. 2. The Alodized panel was given a top coat only. All other panels in the series were primed after the surface treatments with a regular automotive product, baked, given a surface coat dry-scuffed with sandpaper as per standard automotive practice, and then finished with a regular black baked top coat. The panels were removed from the salt spray after failure of the paint film had set in.

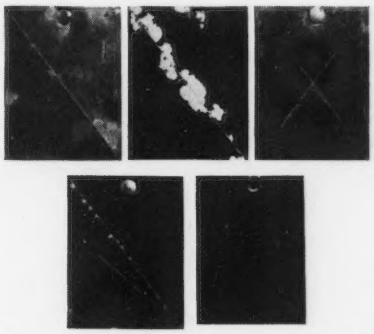

Fig. 2. Salt spray test comparison of Alodine with other surface treatments in retarding underpaint corrosion. (Left to right, top row) alkali cleaned and phosphoric acid dipped—300 hr.; phosphoric acid, solvent cleaned—300 hr.; zinc phosphate coated—400 hr. (Bottom row) anodically oxidized—3000 hr.; Alodized—3000 hr.

## COATING CHARACTERISTICS

The coating produced by this new process is an amorphous metallic phosphate, dense, rather hard, and apparently nonporous. Unlike most oxide films, it is nonabsorptive and cannot be dyed or stained. Sealing in hot water or salts has no apparent effect. It differs markedly in appearance from previously known phosphate coatings, as shown in Fig. 3.

**Electrical Resistance.** Very little information is available at the present time on the electrical properties of the coating, but it is known that resistance increases very rapidly with thickness and as a result coatings normally produced offer extremely high resistance.

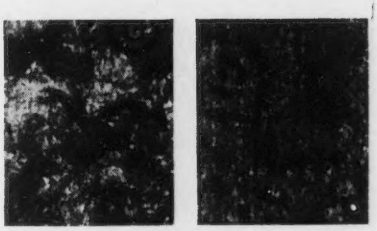

Fig. 3. (Left) conventional phosphate coating on aluminum; (right) Alodine coating produced in 3-min. immersion, rinsed and air dried. Magnification 500 diam.

**Weight and thickness.** Generally speaking, the weight of the amorphous phosphate coating increases with processing time, bath strength, and bath temperature. It is interesting to note that the increase becomes less and less pronounced as the temperature increases and actually reverses itself into a sharp decline between 130 and 140°F.

**Adhesion.** The original purpose in development of this process was to improve adhesion of the paint to aluminum surfaces and thus lengthen their overall life. Only later was it discovered that the film itself provides corrosion resistance.

**Resistance to Bimetallic Corrosion.** Since it has very high surface resistance, the coating, as would be expected, offers good resistance to bimetallic or galvanic corrosion. Test samples are available to illustrate the insulating effects.

*We present here a general and by no means complete, report on ACP Alodine—its properties and uses in protecting aluminum alloys. Your ACP sales representative can give you a much fuller story. Or write us at Ambler.*

*Alodine is a registered trademark of Amchem Products, Inc.

†Since the introduction of Alodine amorphous phosphate coatings, ACP has developed a complete line of Alodine amorphous chromate coatings for superior corrosion resistance.

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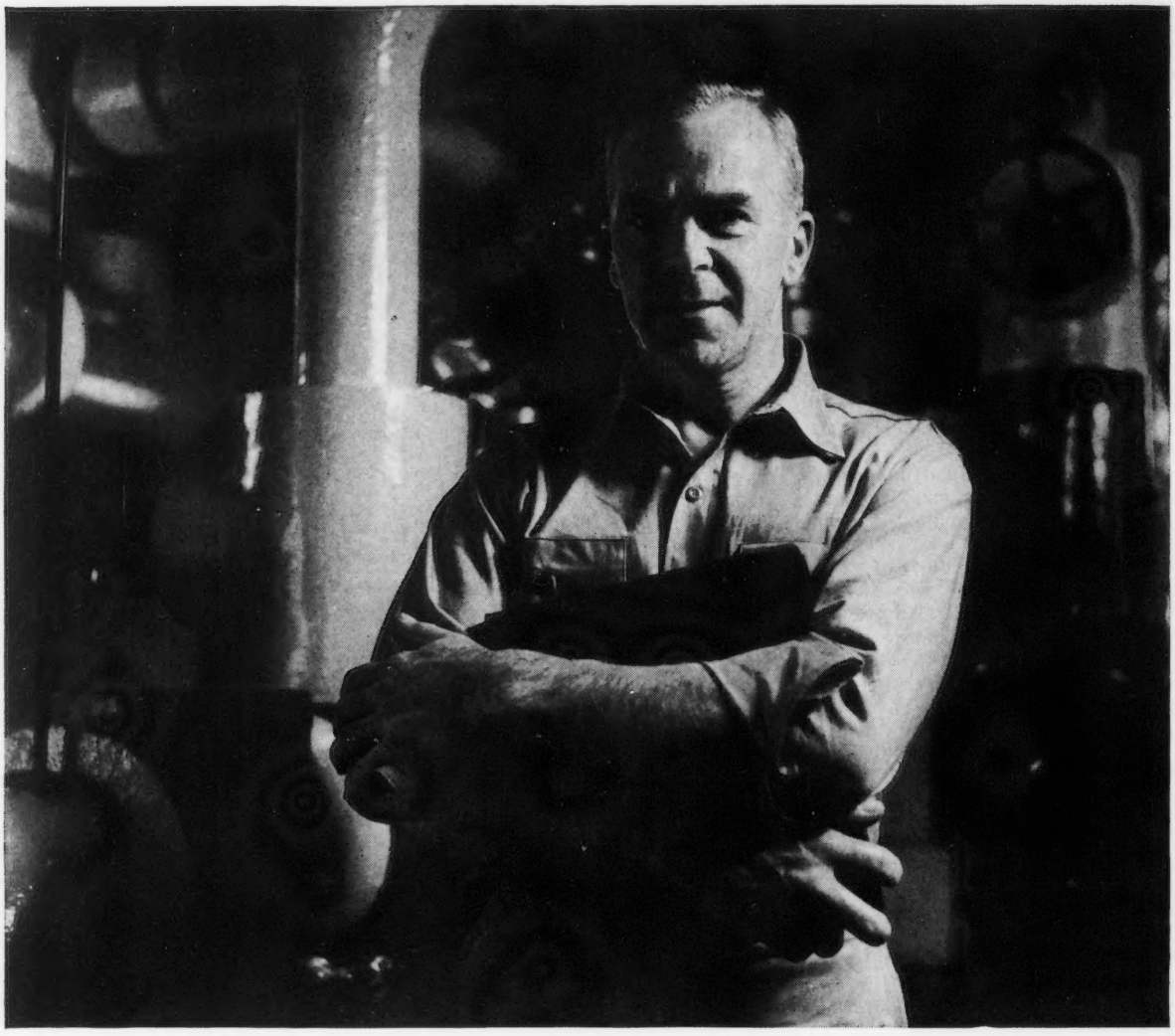

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devoted entirely to corrosion research and control

Published monthly as its official journal, by the National Association of Corrosion Engineers, Inc., at Houston, Texas, U. S. A., as a permanent record of progress in corrosion control.

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*By R. M. Robinson*

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*By F. N. Speller and E. P. Best*

*Turn to Page 12 for List of Articles Scheduled for Publication in November Technical Section.*

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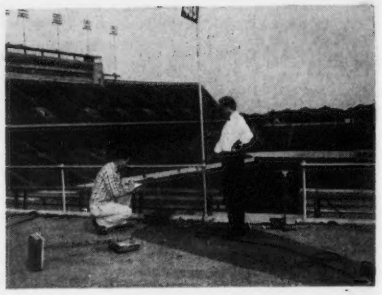

Cathodic Protection Service Photo

**THIS MONTH'S COVER—Engineers are shown here checking the performance of the cathodic protection system on piping installed in the soil fill beneath the concrete concourses at Rice Institute stadium, Houston. No more leaks have occurred since the system was installed several years ago to protect the buried utilities, an intermixture of bare and galvanized steel, cast iron, lead and brass.**


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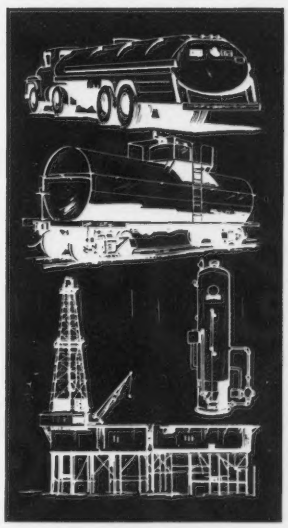

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F. B. Burns, Chairman; Kerr-McGee Oil Industries, Inc., Box 305, Wynnewood, Okla.

***T-2H-5 To Review and Encourage Publication of Technical Articles on Asphalt-Type Protective Coatings***
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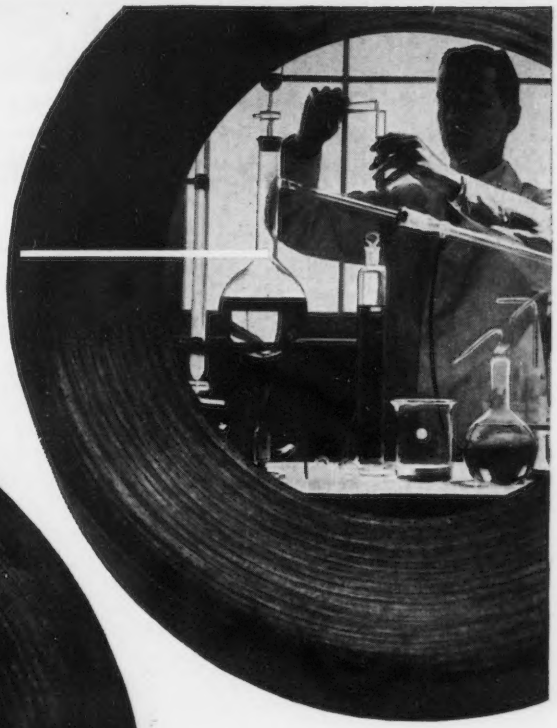

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*T-6B-8 Epoxy (Amine Cured)*

*T-6B-9 Chlorinated Rubber*

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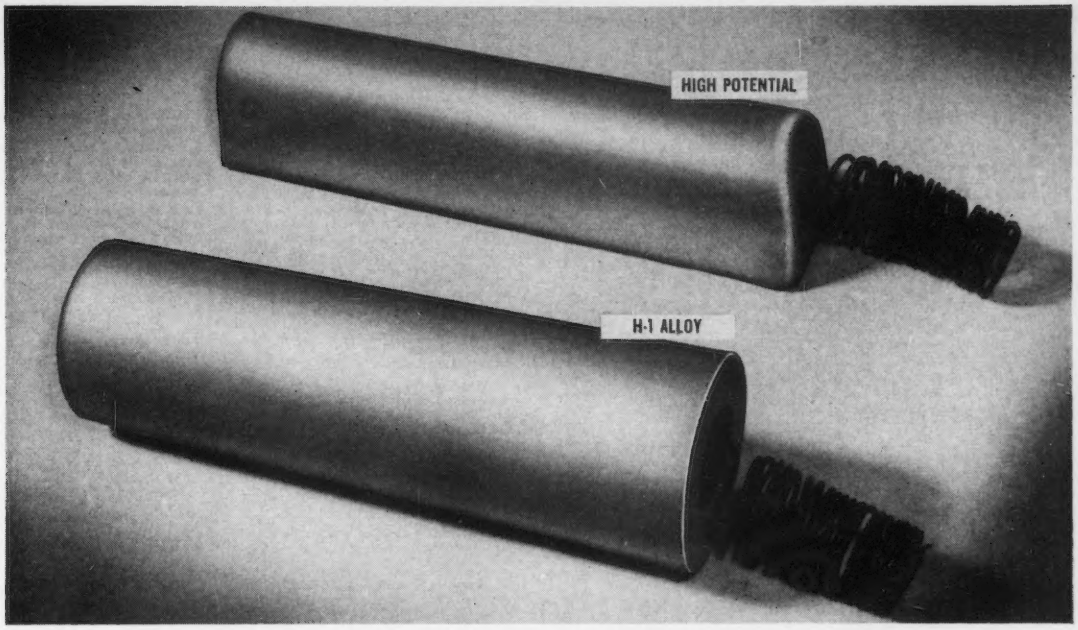


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## TECHNICAL PAPERS SCHEDULED FOR NOVEMBER PUBLICATION

The Electrochemical Behavior of Aluminum—Potential pH Diagram of the System Al-$H_2O$ at 25 C by E. Deltombe and M. Pourbaix

Cathodic Protection of Distribution Systems by Edward F. Fowler

Locating Underground Contacts and Open Couplings by Electrical Measurements by Charles L. Woody

Investigations of Corrosion Mechanisms With the Electron Microscope by R. T. Foley

Observations on the Resistance of Natural Timbers to Marine Wood Borers by C. H. Edmondson. A Contribution to the Work of Group Committee T-9

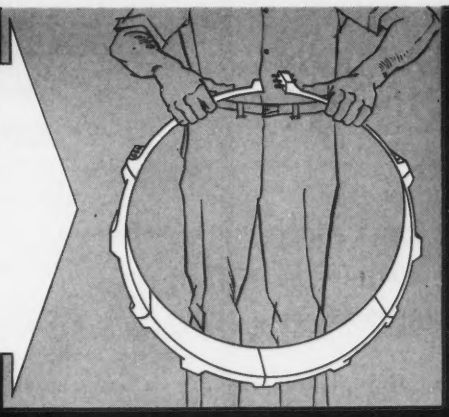
Comparison of Corrosion Engineering or Materials Engineering Functions in Various Chemical Plants by L. W. Gleekman

Corrosion Resistant Steels for Marine Applications by C. P. Larrabee

A Critical Analysis of Pitting Corrosion by M. G. Fontana and N. D. Greene

Laboratory and Field Methods for Quantitative Study of Sulfide Corrosion Cracking by J. P. Fraser, G. G. Eldredge and R. S. Treseder

Influence of Metallurgical Variables on Resistance of Steels to Sulfide Corrosion Cracking by J. P. Fraser and G. G. Eldredge



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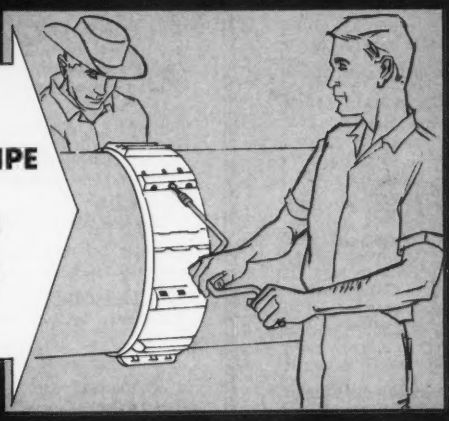

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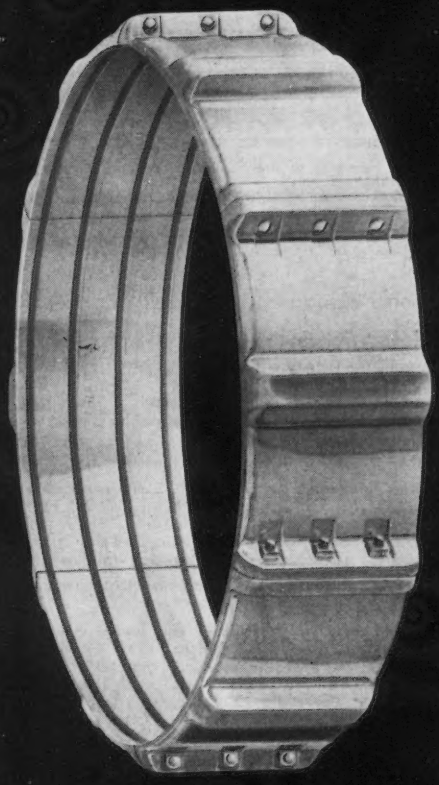

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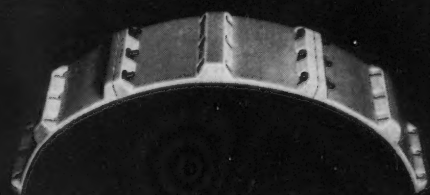

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(a) To promote the prevention of corrosion, thereby curtailing economic waste and conserving natural resources.

(b) To provide forums and media through which experiences with corrosion and its prevention may be reported, discussed and published for the common good.

(c) To encourage special study and research to determine the fundamental causes of corrosion, and to develop new or improved techniques for its prevention.

(d) To correlate study and research on corrosion problems among technical associations to reduce duplication and increase efficiency.

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Corrosion

OFFICIAL MONTHLY PUBLICATION

National Association of Corrosion Engineers

An Association of Individuals and Organizations Concerned with Control of Corrosion

1061 M & M Building Houston 2, Texas

Vol. 14 October, 1958 No. 10

Topic of the Month

# Behavior of Carbon and Stainless Steels in Acid Waters

By R. J. SCHMITT*

THE SUITABILITY of carbon steel as a condenser-tube material for handling fresh waters depends largely upon the formation of protective scales deposited by the water. When fresh water becomes contaminated with acid drainage, the tendency for these protective scales to form is destroyed, and rapid corrosion of carbon steel can be expected. In industrial applications where large volumes of fresh water are handled in a once-through system, treatments other than additions of lime to the water to raise the pH are generally not feasible for preventing corrosion because of cost considerations. The answer to such problems lies in the selection of materials more resistant to corrosion than is carbon steel.

To illustrate, in one coal-chemical plant, 150 million gallons of water contaminated with acid drainage from old coal mines are used daily for cooling purposes. Although the water is treated with lime to raise the pH from about 3.8 to about 4.5 (further treatment being uneconomical because the water is not recirculated), the carbon steel condenser tubes in the wash-oil regenerating system of the plant are corroded severely and fail after about four months of service. (Wash-oil is used to absorb from the coke-oven gas those constituents having boiling points below 200 C, such as benzol, toluol, and xylol.) The wash-oil condenser receives both liquid and vapor wash-oil from a Dowtherm heat exchanger, which partially condenses the oil vapors coming from the wash-oil still. It can be seen from Figure 1 that the hot oil flows through the shell side of the wash-oil condenser and is cooled by river water flowing through the tubes. The temperature of the oil is about 350 F. The cooling water enters the condenser at about 80 F and leaves at about 180 F.

In an effort to reduce the high maintenance and replacement costs caused by the rapid failure of carbon steel tubes, a service test was initiated to determine the suitability of stainless steel tubes in the wash-oil condenser. Four AISI Type 304 (nominally 18 percent Cr and 9 percent Ni) stainless steel tubes and four carbon steel tubes were installed in the tube bundle of the condenser at the same time. After four months of exposure, the carbon steel tubes failed because of severe pitting by the cooling water. After six months exposure, two of the Type 304 tubes removed from the condenser were practically unattacked.

Figure 2 shows a section cut from the center of each type of tube after the service test. The marks seen on the interior surface of the Type 304 tube are fabricational marks. The remaining two Type 304 tubes will be removed after one year of exposure. Because of the excellent resistance of the Type 304 tubes to corrosion by the low pH river water, this type of tube will be installed in the entire condenser. The use of such tubes should result in a substantial yearly savings through decreased maintenance costs.

The 18-8 stainless steels are proving useful in applications such as the one discussed. But from an economic standpoint, service tests in full-scale equipment should be conducted to determine whether requirements can be met with steels having a lower alloy content, since the corrosive constituents of various waters differ greatly in kind and degree.

* Applied Research Laboratory, U. S. Steel Corp., Monroeville, Pa.

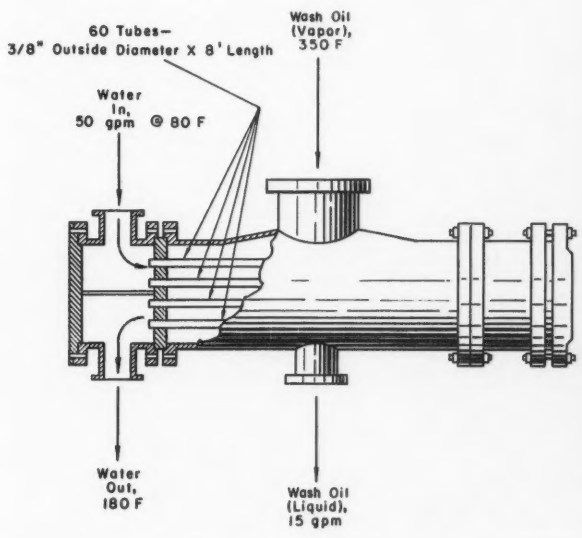


Figure 1—Diagram of wash-oil condenser.

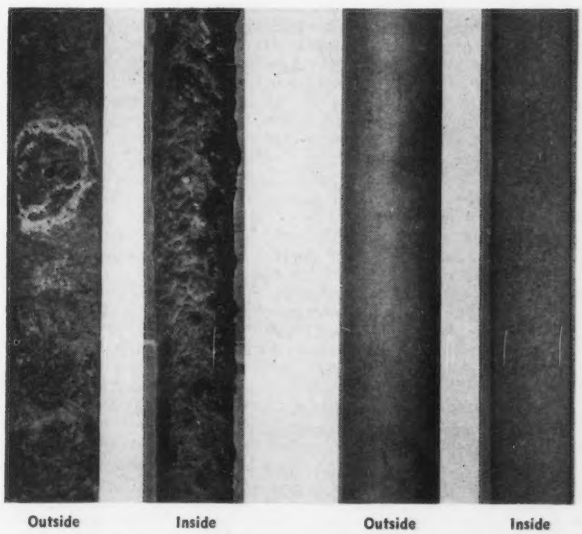


Figure 2—Sections of tubes after exposure in a wash-oil condenser. The tubes in left half of photograph are of carbon-steel and were exposed for four months; tubes in right half of photograph are of AISI Type 304 stainless steel and were exposed for six months. 2X.

# Current and Potential Relations for The Cathodic Protection of Steel in Salt Water*

By W. J. SCHWERDTFEGER*


## Abstract

A laboratory investigation was made pertaining to the cathodic protection of steel specimens that were exposed for 60 days to both stagnant and aerated city water, to which was added 3 percent by weight of sodium chloride.

Major consideration was given to the significance of potential as a criterion for protection. Optimum protection was achieved when specimens were controlled at —0.77 volt with reference to the saturated calomel half cell. Although a good degree of protection was obtained at controlled potentials more noble than —0.77 volt, that is, at the potentials associated with the breaks in cathodic polarization curves, this lesser degree of protection could not be obtained at lower mean current densities. 5.2.4


## Introduction

CATHODIC PROTECTION is applied primarily to iron and steel structures exposed to corrosive soils and waters. Despite the numerous publications on this subject, there still remains a diversity of opinion concerning the criteria for such protection. The fundamental requirements for cathodic protection were established by Mears and Brown[1,2] who concluded that in solutions of high conductivity a metal must be cathodically polarized to the open-circuit potential of the most anodic element on its surface in order to have complete protection.

In an earlier study of cathodic protection at the Bureau, it was observed that the potential of steel exposed to one relatively air-free soil (pH 9.5) was about —0.77 v with reference to a saturated calomel half cell.[3] It also was observed that a composite curve of pH versus potential of steel, as obtained from measurements in 20 air-free soils, intersected the pH-potential curve of the standard hydrogen electrode at pH 9 and approximately —0.77 v. In tests which followed, steel maintained for 60 days at about —0.77 v lost very little weight in five severely corrosive soils. This potential is equivalent to —0.85 v referred to the copper-copper sulfate electrode. These laboratory results thus confirmed the field experience of Kuhn[4] and many others. A pertinent observation was made by Sudrabin[5] in that iron in an air-free sea water environment was found to have a potential of —0.77 v with reference to the saturated calomel half cell.

Some engineers are of the opinion that —0.85 v with reference to a copper-copper sulfate electrode sometimes represents overprotection and excessive current demands. In order to investigate the matter further, the present work was undertaken.

Cathodic polarization curves are logically associated with any study in cathodic protection. The current at the break (change-in-slope) in the curve, which occurs at the open-circuit potential of the anode of a corrosion cell or at the composite open-circuit potential of all the anodes on a corroding steel surface, has been found to bear a relatively direct relationship to the corrosion current.[6] This current is the minimum value necessary for cathodic protection, based on the corrosion rate existing at the instant of measurement and has been discussed previously in connection with the cathodic protection of steel in soils.[3] The minimum current for cathodic protection also has been discussed by Pope.[7]

In order to relate the current at the break in the curve with the currents and the potential required to maintain optimum protection, an investigation was conducted with a water environment containing 3 percent of sodium chloride. This environment was chosen as the IR drop is negligible in such a medium and therefore potentials measured with the equipment used would be significant.

## Experimental Procedures

### *General*

All specimens used in these experiments were cut from one piece of 0.5 inch diameter cold-rolled steel to lengths of 16 inches. They were degreased, smoothed with emery cloth, washed in hot water, and then weighed to the nearest 5 mg.

The exposure medium was Washington, D. C., city water to which had been added 3 percent by weight of sodium chloride, each specimen being exposed for a period of 60 days. Exposure was under two conditions, one with the electrolyte in Pyrex jars (approximately 12 inches in diameter by 12 inches high) representing a stagnant condition, and the other in the electrolyte in an aerated condition when contained in a wooden vat about 66 inches in diameter and 18 inches high. Air was continually passed into the salt water in the vat from a perforated rubber hose which rested on the bottom. In both cases, water lost by evaporation was replaced weekly. No attempt was made to control the temperature of the electrolyte, and exposure of the specimens in the jars was not simultaneous with exposure of those in the vat. All of the specimens were positioned normal to the surface of the electrolyte with 0.1 sq ft of bare surface under exposure.

Specimens were protected from waterline corrosion by plastic insulating tape extending about 1.5 inch above and below the waterline thus allowing about 9 inches of the steel to be exposed. The surface of the specimens above the tape was protected against atmospheric corrosion with a thin coating of oil.

At the conclusion of exposure all specimens were removed from the electrolyte, washed under hot running water, and examined. Tightly adherent corrosion products were loosened by cathodically cleaning the specimens in the same electrolyte at a current density of 1 amp/sq ft for periods ranging from 1 to 3 hours. This was followed by brushing with a stiff brass bristle brush under hot running water. When dry, the specimens were again wire brushed and reweighed to measure loss of metal.

### *Arrangement for Stagnant Exposure*

Five jars were filled to within 1 inch from the top with the sodium chloride solution. Four of the jars were each fitted with three 0.5 inch diameter carbon anodes mounted vertically 0.5 inch from the inner wall so as to form the corners of a triangle and extending about 3 inches above the waterline. One specimen was located at the vertical center line of each jar and held by a perforated rubber stopper with a clamp, so that its lower end did not quite reach the bottom of the jar.

Electrical connections to the anodes and specimens were made with battery clips, the three anodes being intercon-

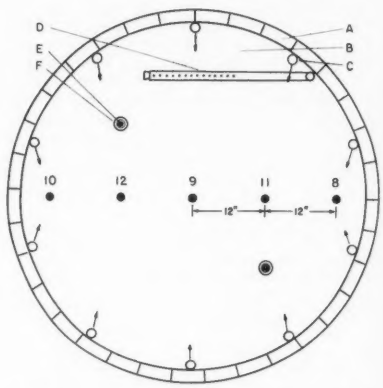


Figure 1—Experimental arrangement in wooden vat. Control specimens are Nos. 8, 9 and 10; cathodically protected specimens are Nos. 11 and 12.

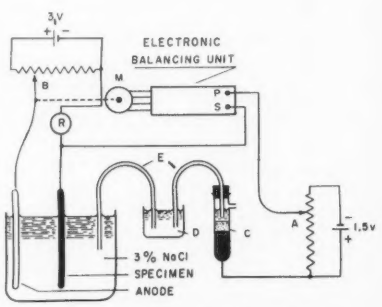


Figure 2—Potential-control circuit.

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nected. Wires from the clips were securely fastened to the outside of the jars so as to avoid disturbing the specimens when making electrical connections. The fifth jar was not fitted with carbon anodes but contained two control specimens, No. 1 centrally mounted and No. 6 off to the side about 1 inch from the inside wall of the jar.

Three of the four jars with the carbon anodes contained specimens that were held under different degrees of cathodic protection. The fourth jar contained control specimen No. 2. Sleeves of insulating material were vertically mounted near the inner wall of each jar with one end of the sleeve extending about 5.5 inches below the waterline in order to hold an agar salt bridge. The bridge consisted of a flexible plastic tube containing a cotton string saturated with potassium chloride and filled with a saturated potassium chloride-agar mixture. This connected the test solution with the reference cell.

*Arrangement for Aerated Exposure*

The location of specimens Nos. 8 through 12 in the wooden vat, A, is shown in Figure 1. They too were fitted with perforated rubber stoppers for clamping to a supporting bar which spanned the open top of the vat. The electrolyte, B, was maintained to a depth of 17 inches and the exposed ends of the specimens were about 6.5 inches from the tank bottom.

Anodes, C, consisting of 0.5 inch diameter steel rods mounted as shown, were used to supply current for the specimens as needed. Two anodes were used in conjunction with each specimen as indicated by the arrows. Steel rather than carbon anodes were used in order to avoid excessive anodic polarization of the anodes when obtaining cathodic polarization curves automatically on the specimens. Electrical connections with the specimens and anodes were made as previously described.

The air hose, D, end sealed, contained 15 holes 1 inch apart. In anticipation of the likelihood of uneven water movement around the five specimens, the cathodically protected specimens (Nos. 11 and 12) were symmetrically arranged with respect to the air supply. Visual observation and later experimental results indicated maximum agitation in the center of the tank, with decreasing agitation toward the tank wall. The flexible agar-salt bridges, E, used in conjunction with the potential-control equipment for specimens Nos. 11 and 12, were held by insulated sleeves, F, as previously mentioned.

*Instrumentation*

All potentials were measured with reference to the saturated calomel half cell using an indicating potentiometer. Some specimens were held at a constant current in the stagnant water while others were held at constant potential. The constant current was supplied from 4 series-connected heavy duty 1.5 v dry cells and appropriate series resistance. After the initial polarization of the carbon anodes, the current remained within about 2 percent of the desired value. The constant potential was controlled by the circuit shown in Figure 2 to within ±5 mv of the adjusted value. The voltage divider, A, was set at the desired potential with reference to the half cell, C. Any difference of potential between terminals PS caused the balancing motor, M, to operate the voltage divider, B, until the difference of potential was reduced to zero. As previously stated, the IR drop through the electrolyte was negligible. Two agar-salt bridges, E, connected the test solution with the reference cell, C, through a container of saturated potassium chloride, D. When specimens were protected at a designated potential, the polarizing current was continuously recorded by a strip chart recorder, R.

Cathodic polarization curves were obtained on most of the controls at significant times throughout the exposure periods and occasionally on some of the specimens under cathodic protection. The polarizing current and potential of the specimen were recorded with a two-pen strip chart electronic recorder, the potential measuring circuit of which has a high input impedance. The polarizing current was supplied by a 4 v storage battery shunted by a voltage divider which was manually controlled during stagnant exposure and synchronously driven during aerated exposure.

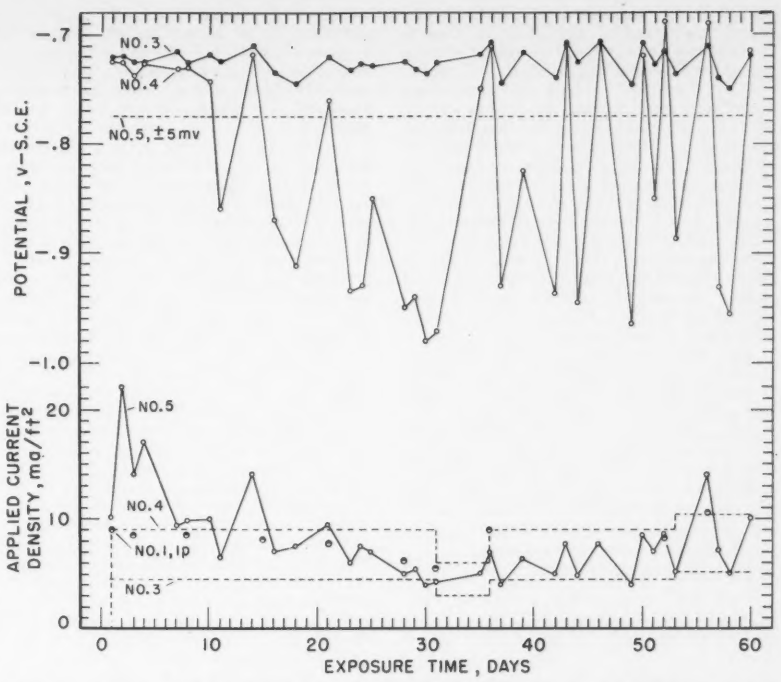


Figure 3—Relationship between potential and applied current density for different degrees of cathodic protection on steel specimens Nos. 3, 4 and 5 exposed to stagnant water containing 3 percent of sodium chloride. $I_p$, protective current requirement as indicated by control specimen No. 1; No. 5, specimen at constant potential —0.77 volt; No. 4, specimen at constant current, except as indicated; No. 3, specimen at constant current equal to 50 percent of that on No. 4.

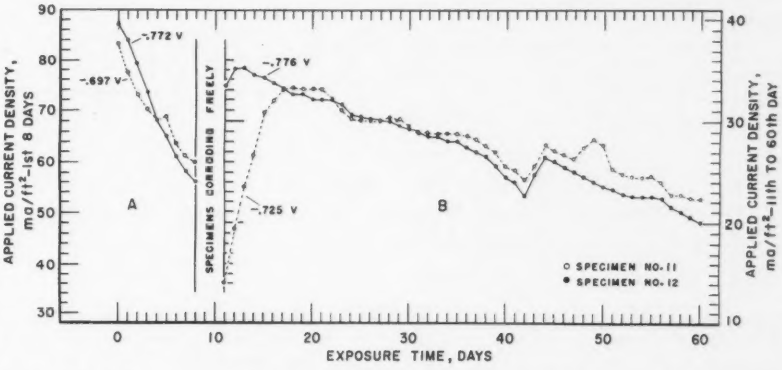


Figure 4—Protective current densities on steel specimens exposed to aerated water containing 3 percent of sodium choride when controlled at constant potentials. "A" represents protective current applied immediately upon exposure; "B" represents protective current applied to the same specimens after an intermediate freely corroding period of three days.

## Experimental Results

*Exposure to Stagnant Salt Water*

For the first 24 hours of exposure all of the specimens corroded freely. It was assumed that all six would corrode at approximately the same rate as the exposed areas were equal and the environment the same. On the second day, cathodic polarization curves were obtained on the control specimens Nos. 1 and 2. The current, $I_p$, at the break in the curve, approximately the same

value being measured for both specimens, was applied to specimen No. 4. A current equal to 50 percent of this value of $I_p$ was applied to specimen No. 3. Potential control was placed on specimen No. 5, the controller being adjusted to —0.775 v. The potential of specimens 3 and 4 and the current to specimen 5, measured daily or less frequently throughout the exposure period, are plotted in Figure 3. Also shown in Figure 3 are the values of current, $I_p$, from curves obtained less frequently on control specimen No. 1 at significant times during the exposure period. The values of current shown in Figure 3 and wherever later mentioned have been converted to current densities.

The plots of the potentials of specimens Nos. 3 and 4 and of the current to specimen No. 5 (Figure 3) show that fluctuations such as occurred in the corrosion rates, due chiefly to temperature changes of the electrolyte, happened more or less simultaneously. For example, any depolarization of specimens No. 3 and 4, indicative of increases in corrosion rate, was generally accompanied by increased current to specimen No. 5, while increased polarization of specimens Nos. 3 and 4 was usually associated with decreased current to specimen No. 5. That the current at the break in the polarization curve is a critical value, as related to polarization, is shown by the values of current $I_p$ (No. 1 specimen) and the potential changes of specimen No. 4, presumably held fairly close to a mean value of $I_p$ considered applicable to all specimens.

It will be observed that an over-all lowering of the corrosion rate occurred up to about the 31st day of exposure, as indicated by the decreasing values of $I_p$ for specimen No. 1. The low rates of corrosion on the 28th and 31st days of specimen No. 1 are reflected in the potential of specimen No. 4, which at the time had more protective current applied than was then required. Accordingly, it was decided to reduce the current to specimen No. 4 and also to specimen No. 3 as shown (Figure 3).

On the 36th day, it was noticed that considerable depolarization had occurred on specimen No. 4, some on specimen No. 3, and that the current to specimen No. 5 had increased. That these observations were indicative of increased rates of corrosion was verified by an increase in current $I_p$ from the curve on control specimen No. 1, obtained on the 36th day, to approximately its original value. Accordingly therefore, the currents to specimens Nos. 3 and 4 were again raised, No. 4 to the value indicated by the then currently measured $I_p$ and No. 3 to 50 percent of that value. On the 52nd day, an unusually large amount of depolarization had occurred on specimen No. 4. Therefore, on the following day, the current applied to this specimen was again raised slightly.

During the remainder of the test, the potential of specimen No. 4 and the current to specimen No. 5 continued to fluctuate. However, a cathodic polarization curve obtained on control specimen No. 1 on the 56th day indicated $I_p$ to be very nearly the same as the current applied to specimen No. 4. During this period the current to specimen No. 3 was increased accordingly.

All specimens were subject to fluctuations in temperature of the salt water because the room temperature varied from 60 to 92 F during the exposure period. As would be expected, increases in temperature were accompanied by increased rates of corrosion and decreases in temperature resulted in lower rates of corrosion. The effect was particularly noticeable by the potential changes that occurred on specimen No. 4. Although these effects were not premeditated, the changes in corrosion rate on specimen No. 4 made it possible to observe the effects, on potential, of applied current less and greater than the critical value, $I_p$, as this value fluctuated above and below the applied value.

**TABLE 1—Exposure for 60 Days to Stagnant Water Containing 3 Percent of Sodium Chloride**

| Exposure Period | Specimen Number | Protective Criterion | CATHODIC POLARIZATION CURVE: Current at Break, $I_P$ Range Min., ma/ft² | Range Max., ma/ft² | Mean, ma/ft² | Potential at Break, $E_B$[a] Range Min., v | Range Max., v | Mean, v | PROTECTIVE CURRENT TO SPECIMEN Range Min., ma/ft² | Range Max., ma/ft² | Mean, ma/ft² | POTENTIAL OF SPECIMEN[a] Range Min., v | Range Max., v | Mean, v | Corrosion Current[b] I, ma/ft² | Weight Loss of Specimen 60 Days, mg | Effectiveness of Protection[c], % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1st 24 hrs | All specimens corroding freely | | | | | | | | | | | | | | | | |
| Remainder, 59 days | 1 | Control | 5.5 | 10.5 | 8.0 | —0.740 | —0.775 | —0.763 | .... | .... | .... | —0.685 | —0.735 | —0.719 | 6.1 | 920 | .... |
| | 2 | Control | 8.5 | 10.5 | 9.1 | —.760 | —.775 | —.768 | .... | .... | .... | —.710 | —.730 | —.722 | 6.9 | 1035 | .... |
| | 3 | Current | .... | .... | .... | .... | .... | .... | 3.0 | 5.2 | 4.4 | —.706 | —.750 | —.726 | .... | [e]435 | 54 |
| | 4 | Current | .... | .... | .... | .... | .... | .... | 6.0 | 10.4 | 8.8 | —.688 | —.980 | —.843 | .... | [e]120 | 87 |
| | 5 | Potential | .... | .... | .... | .... | .... | .... | 4.0 | 22.0 | [d]7.4 | —.770 | —.780 | —.775 | .... | [e]20 | 98 |
| | 6 | Control | .... | .... | .... | .... | .... | .... | .... | .... | .... | —.690 | —.733 | —.720 | 5.8 | 865 | .... |

[a] Saturated calomel scale.
[b] Based on Faraday's law, $W = KtI$, where $K = 2.8938 \times 10^{-4}$ grams per coulomb, $W$ = wt. loss of control.
[c] Effectiveness of protection $= \frac{Wc - Wp}{Wc} \times 100$, where $Wc$ = avg. wt. loss of controls, $Wp$ = wt. loss of the cathodically protected specimen.
[d] Based on hourly values from the strip chart record.
[e] Corrected for freely corroding period.

**TABLE 2—Exposure for 60 Days to Aerated Water Containing 3 Percent of Sodium Chloride**

| Exposure Period | Specimen Number | Protective Criterion | CATHODIC POLARIZATION CURVE: Current at Break, $I_P$ Range Min., ma/ft² | Range Max., ma/ft² | Mean, ma/ft² | Potential at Break, $E_B$ Range Min., v | Range Max., v | Mean, v | PROTECTIVE CURRENT TO SPECIMEN[d] Range Min., ma/ft² | Range Max., ma/ft² | Mean, ma/ft² | POTENTIAL OF SPECIMEN[a] Range Min., v | Range Max., v | Mean, v | Corrosion Current[b] I, ma/ft² | Weight Loss of Specimen 60 Days, mg | Effectiveness of Protection[c], % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1st 8 days | 8 | Control | .... | .... | 20.0 | .... | .... | —0.725 | .... | .... | .... | —0.655 | —0.700 | —0.686 | .... | .... | .... |
| | 9 | Control | .... | .... | 30.0 | .... | .... | —.730 | .... | .... | .... | —.652 | —.695 | —.681 | .... | .... | .... |
| | 10 | Control | .... | .... | 22.5 | .... | .... | —.730 | .... | .... | .... | —.647 | —.700 | —.684 | .... | .... | .... |
| | 11 | Potential | .... | .... | .... | .... | .... | .... | 60.0 | 95.0 | 70.7 | —.685 | —.700 | —.697 | .... | .... | .... |
| | 12 | Potential | .... | .... | 51.0 | .... | .... | —.680 | 56.0 | 90.0 | 70.2 | —.770 | —.780 | —.772 | .... | .... | .... |
| 8th to 11th day | Specimens 11 and 12 corroding freely for 72 hours | | | | | | | | | | | | | | | | |
| 11th to 60th day | 8 | Control | 20.0 | 22.5 | 21.2 | —0.725 | —0.735 | —0.728 | .... | .... | .... | —0.690 | —0.715 | —0.705 | 13.9 | 2,090 | .... |
| | 9 | Control | 27.5 | 33.0 | 30.2 | —.705 | —.730 | —.715 | .... | .... | .... | —.670 | —.702 | —.689 | 19.7 | 2.955 | .... |
| | 10 | Control | 19.0 | 22.5 | 20.5 | —.725 | —.730 | —.728 | .... | .... | .... | —.690 | —.712 | —.704 | 15.3 | 2.300 | .... |
| | 11 | Potential | .... | .... | 28.0 | .... | .... | —.730 | 13.5 | 34.2 | 27.5 | —.720 | —.733 | —.725 | .... | [e]238 | 90 |
| | 12 | Potential | .... | .... | 28.0 | .... | .... | —.730 | 20.0 | 36.0 | 27.6 | —.770 | —.780 | —.776 | .... | [e]108 | 95 |

[a] Saturated calomel scale.
[b] Based on Faraday's law, $W = KtI$, where $K = 2.8938 \times 10^{-4}$ grams per coulomb, $W$ = wt. loss of control.
[c] Effectiveness of protection $= \frac{Wc - Wp}{Wc} \times 100$, where $Wc$ = avg. wt. loss of controls, $Wp$ = wt. loss of the cathodically protected specimen
[d] Based on hourly values from the strip chart record.
[e] Corrected for freely corroding period.

At the end of the 60-day exposure period, in turn, protective currents were removed from specimens Nos. 3, 4, and 5 and depolarization allowed to proceed to the most noble potentials. In each instance, the depolarization time was about 20 minutes, specimen No. 5 reaching the most noble potential of the three specimens, followed in the order of potential by specimens Nos. 4 and 3. Based on previous experience with the cathodic protection of steel in soils,[3] these relative changes in potential indicated that specimen No. 5 probably had received the best degree of protection. That this was true will be shown later with reference to the weight losses measured on these specimens.

Table 1 shows pertinent data resulting from the experiment. The weight losses of the cathodically protected specimens have been adjusted to allow for the first 24 hours of exposure when all specimens were corroding freely. This adjustment was made by substituting the value of $I_p$, measured on the controls during the second day of exposure, in the Faraday equation and deducting the calculated weight loss from the total measured weight loss.

The data show virtually complete protection of specimen No. 5 maintained at the protective potential and also at a lesser average current than was applied to specimen No. 4, which was not as effectively protected. These data show that steel must be continuously polarized at least to the potential at the break in the cathodic polarization curve in order to achieve a good degree of protection. Based on the cathodic polarization curves (Table 1) this value, $E_a$, peculiar to the type of environment, was around —0.765 v (mean of specimens Nos. 1 and 2). Although the mean polarized potential of specimen No. 4 was —0.843 v (overprotection), there were times when the potential was more noble than —0.765 v, probably accounting for most of the additional weight loss over specimen No. 5. By referring to Figure 3, and considering —0.775 v as a datum line, it will be observed how often the potential of specimen No. 4 reflected insufficient protection. It is believed that the greatest weight loss on specimen No. 4 occurred during the first 10 days when polarization was inadequate.

Other important points brought out by these data, which are in agreement with results previously obtained for soil exposure, are that the current $I_p$ is a measure of the minimum value required to produce adequate polarization (with time) and that lesser values initially applied, for example as on No. 3 specimen, result in only partial protection.

The ratio between the corrosion current and the current required to prevent corrosion is about 0.85. This ratio is based on the average corrosion current figured for the three controls and the mean current applied to specimen No. 5 (Table 1). For steel in soils, this ratio varied from 0.78 to 0.88, based on the current $I_p$.[6]

*Exposure to Aerated Salt Water*

For the experiment in aerated water it was decided to hold one specimen No. 11, at about the potential corresponding to that at the break in the cathodic polarization curve (designated $E_a$), and the other at —0.77 v. This experiment was designed primarily to determine whether it is advantageous to protect at a potential more noble than —0.77 v, and also to determine the comparative protective currents required in stagnant and agitated waters. The average water temperature during exposure was 74 F, ranging between 66 and 88 F and never varied more than 5 degrees in 24 hours.

Unlike the test in stagnant water, the protective currents were initially applied to specimens Nos. 11 and 12 immediately upon immersion. A preliminary polarization curve obtained upon a control specimen furnished the basis for the initial control of specimen No. 11 at about —0.7 v while specimen No. 12 was adjusted for control at —0.775 v.

After applying protection it soon was observed that the protective currents, automatically recorded, were unusually high. These currents, plotted in Figure 4, are daily averages based on hourly values from the strip charts.

The potentials shown are the mean measured values. It will be noted that, even after eight days, the current densities are still high. On the previous day (seventh day), cathodic polarization curves had been recorded on the freely corroding controls Nos. 8, 9, and 10. The values of $I_p$ from these curves, tabulated in Table 2, showed that protection of the controls could have been accomplished at less than half the current applied to specimens Nos. 11 and 12, even after the latter two had been under cathodic protection for eight days. On the eighth day of exposure, the current to specimen No. 12 was removed and in a period of 60 seconds the specimen potential rose to —0.46 v and then began slowly to drift back again in the less noble direction. After a lapse of 50 minutes the potential was —0.57 v, changing very little compared to previous changes. A cathodic polarization curve was then obtained on specimen No. 12, resulting in the values of $I_p$ and $E_a$ tabulated in Table 2 (first eight days). One hour later, an anodic polarization curve was recorded on this specimen (not recorded in Table 2). These curves revealed that the corrosion process was cathodically controlled and at a relatively high corrosion rate, as indicated approximately by the cathodic polarization current $I_p$.

Apparently the protective currents to specimens Nos. 11 and 12 were high, for the first eight days at least, because no time was allowed for a normal corrosion rate to become established. After obtaining the polarization curves on specimen No. 12, both specimens were left without any protection for three days by removing the protective currents. After corroding freely during this time, cathodic polarization curves were again obtained (11th day). The new values of $I_p$ (28 ma/ft$^2$, Table 2) were more consistent with the values previously obtained for the controls and the intermediate values of $I_p$ seem reasonable when considering the positions in the vat of specimens Nos. 11 and 12 relative to the controls. On the 11th day of exposure, these specimens were again placed under cathodic protection.

Because the potentials $E_a$ (Table 2), previously obtained from curves of the controls, were all more anodic than —0.70 v it was expedient to readjust the control potential for specimen No. 11. Accordingly, specimen No. 11 was adjusted to —0.725 v and No. 12 again at —0.775 v. The currents applied to these specimens, automatically recorded for 60 days are, are tabulated in Table 2 and daily averages are plotted in Figure 4. The potential of specimen No. 12 also was automatically recorded for the 60 days and, in addition, daily measurements of potential were made on all other specimens, including No. 12. Minimum, maximum, and mean values are tabulated in Table 2.

The values of $I_p$ and $E_a$ shown for the controls (Table 2, 11th to 60th day) are based on all curves, that is, those recorded on the 7th, 39th, and 57th days of exposure. Judging from the mean values of $E_a$ for the controls, it would be expected that the composite open-circuit potential, $E_a$, of the anodes of specimen No. 11, and for that matter also specimen No. 12, probably was between —0.715 and —0.728 v. Thus, this range gave assurance that the potential, —0.725 v, to which specimen No. 11 was controlled, was about right, the value —0.73 v shown in Table 2 for this specimen being based on only one measurement made the 11th day. On the 60th day, when the protective currents were removed, the rise in potential, as previously described for the cathodically protected specimens in the stagnant water, indicated that specimen No. 12 received the best degree of protection.

The weight loss data (Table 2) indicate that the effectiveness of the cathodic protection was best on specimen No. 12 and also favorable from the standpoint of applied current over the latter portion of the exposure period (Figure 4). While investigating the reasons for the high currents initially required to protect specimens Nos. 11 and 12, it was decided to hold control specimen No. 8 at a protective potential of —0.775 v overnight and automatically record the protective current required. After 20 hours of cathodic protection, the potential was changed progressively over a period of 10 minutes to a value of —0.700 v (Figure 5). Within 1 hour, the initially reduced current had increased until it was almost as high as previously. Upon again gradually readjusting the potential to —0.775 v, which required an initial increase of current, a gradual reduction followed, the current once again approaching the original value. This experiment confirmed the comparative currents applied to the cathodically protected specimens Nos. 11 and 12. In fact, the data seem to indicate that protection at the potential —0.77 v not only assures virtually complete protection but also optimum current requirments.

The average weight loss of the controls in aerated water was about 2.6 times that in stagnant water whereas 3.7 times as much current was required for protection. Had the exposure of the steel in the aerated water been prolonged until the protective current on specimen No. 12 (Figure 4) was stabilized, the ratio of the currents might have been more in agreement with the ratio of the weight losses. It is believed that the higher protective current ratio may be attributed in part, to a difference in the degree of cathodic control of the corrosion rates under the two conditions of exposure. A somewhat analogous comparison of protective currents was made by Waldron and Nelson[8] in reference to the cathodic protection of ship hulls. They found that approximately twice as much current was required to maintain a given potential when a ship was moving as when it was stationary.

## Summary

Cold-rolled steel specimens were exposed for 60 days to both stagnant and aerated city water, to which was added 3 percent by weight of sodium chloride.

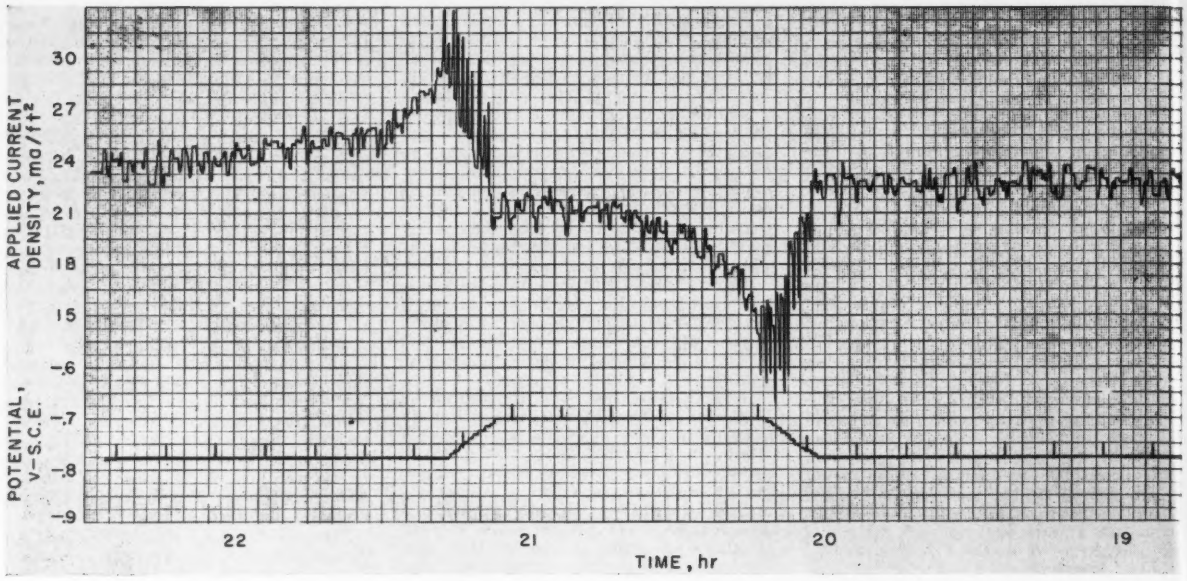


Figure 5—Recorded chart showing the variation of the cathodic current density of a steel specimen when changing from potential control at —0.775 volt to control at —0.700 volt and back again. The potential was initially —0.775 volt for 20 hours.

Under both stagnant and aerated exposure, the best degree of cathodic protection was achieved when the specimens were held at a potential —0.77 v with reference to the saturated calomel electrode (equivalent to —0.85 v with reference to the copper-copper sulfate electrode). Although a good degree of protection was obtained at controlled potentials more noble than —0.77 v, that is, at the potentials associated with the breaks in cathodic polarization curves, this lesser degree of protection could not be obtained at lower mean current densities. Therefore, —0.77 v was found to be the optimum protective potential.

Applied currents indicated by the breaks in cathodic polarization curves agreed reasonably well with the currents required to maintain polarization at the optimum potential. The break current, therefore, which was observed to be related to the rate of corrosion, is considered a good measure of the current required for optimum protection.

A short preliminary period of exposure without protective current was observed to greatly reduce the amount of current initially required for cathodic protection.

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**Any discussions of this article not published above will appear in the June, 1959 issue**

# Records Related to a Natural Gas Distribution Corrosion Control Program*

By LEONARD C. HILL


## Abstract

This paper is concerned with general policy procedure and useful recording of data relative to corrosion control in some 169 retail distribution systems. Some 115 of these systems are all painted and wrapped and under complete cathodic protection; the remaining 54 towns are spot protected. Since 1944 all new construction has been painted and wrapped, isolated into convenient sections, all meter sets insulated and cathodic protection applied. Recording procedure is discussed and illustrated as is also the manner in which leakage data are kept.

Annual current and potential surveys are made by a corrosion technician and monthly potential checks are made by district personnel. Occasional training schools are responsible for the satisfactory maintenance of protection by district personnel with a minimum of assistance from corrosion technicians. Illustrations of data use and records are discussed.

Practical aspects of this program are considered briefly although cost records are not specifically discussed. 8.4.2


## Introduction

KANSAS-NEBRASKA Natural Gas Company, Inc., an integrated operation, is actively engaged in the production, transmission and distribution of natural gas, at both the retail and wholesale levels in Oklahoma, Kansas, Nebraska and eastern Colorado. This paper is concerned with an examination of this company's generalized policy procedure and some of the useful recorded data used in connection with corrosion control in 169 retail towns. Some 115 of these towns have systems which are all coated and wrapped and under full cathodic protection. The remaining 54 towns are spot-protected or protected by sections —generally new additions or replacements.

Early experiences with corosion and its control, plus management's positive attitude, brought full and active cooperation from the supervision of each department in the author's company. Today, corrosion control procedures are not considered special projects; rather, they are as much a part of any job as is welding or pipe-fitting. Corrosion control has been in use in this company for approximately 20 years in transmission, 15 years in distribution and 12 years in production.

The Corrosion Department is a separate unit of the company. It is comprised of a chief corrosion engineer, five technicians and a small installation and maintenance crew. Division and district personnel assist in the corrosion control program through generalized policy procedure. New work is set up for corrosion control during the engineering de-


About the Author

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★ Submitted for publication October 16, 1957. A paper presented at a meeting of the South Central Region, National Association of Corrosion Engineers, Oklahoma City, Oklahoma, October 1-4, 1957.

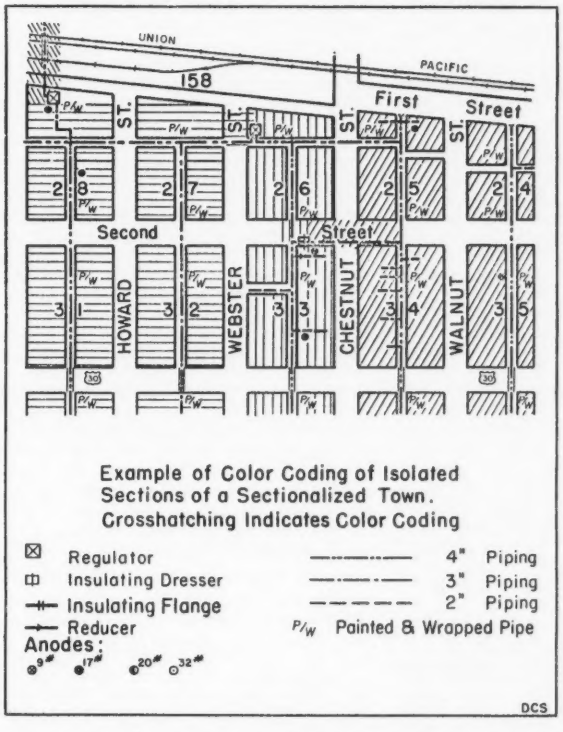


Figure 1—Example of color coding of isolated sections of a sectionalized town. Crosshatching indicates color coding.

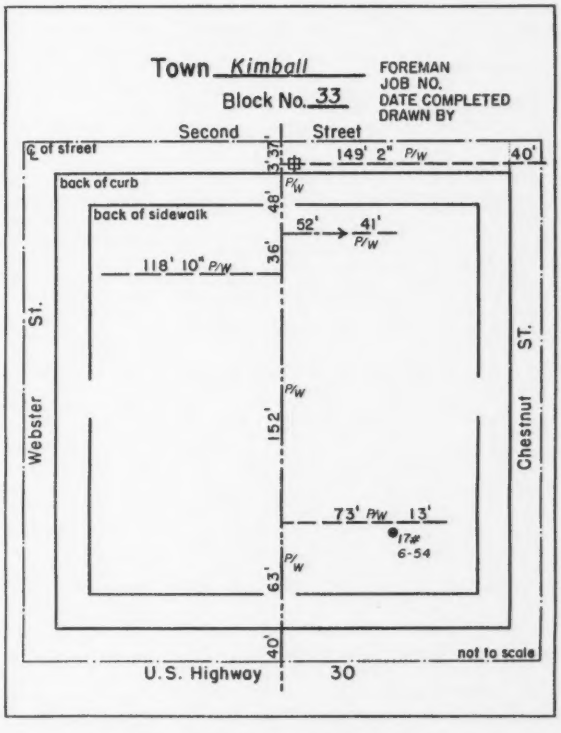


Figure 2—Application of data to block card record.

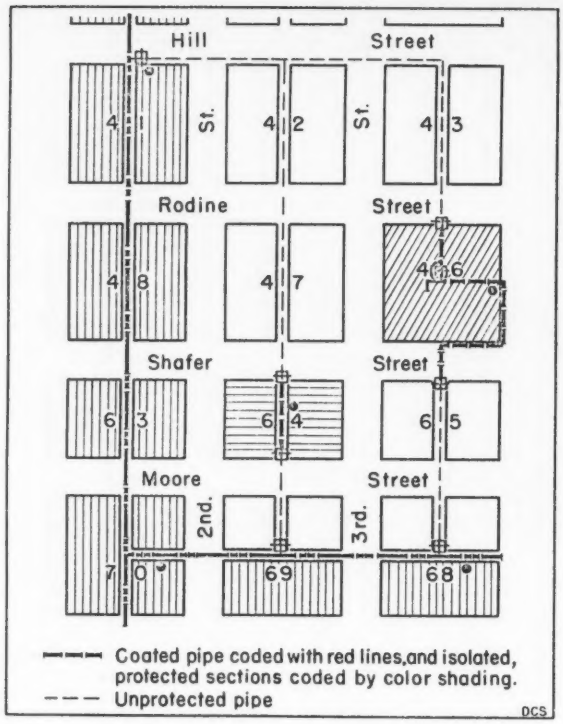


Figure 3—Map showing coated and unprotected pipe.

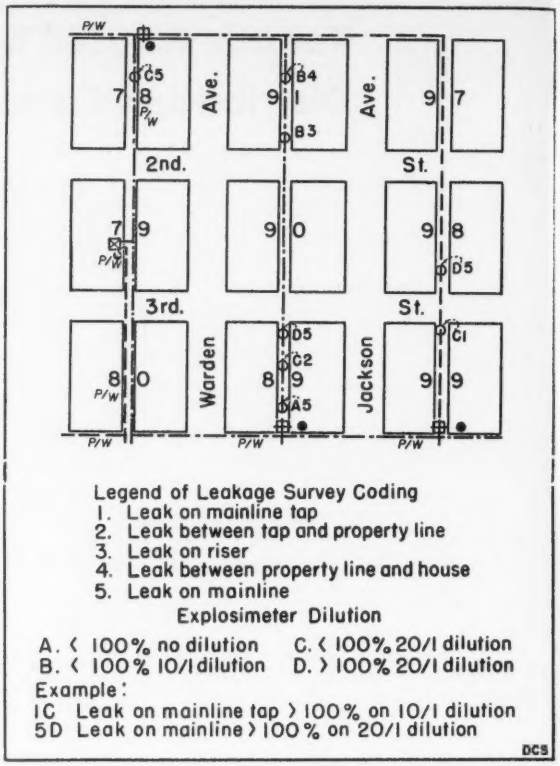


Figure 4—Leakage survey map.

**Monthly Cathodic Report**

Broken Bow, Nebraska — Month Sept.

Annual Check, June 12, 1957

| Location | | Main | Service | P.D. | Present P.D. |
|---|---|---|---|---|---|
| | **Business District** | | | | |
| Block 177 | Brown McDonalds | 1.37 | .51 | 830 | 840 |
| Block 107 | Burlington Hotel | 1.39 | .53 | 850 | 820 |
| Block 139 | Nelson-Maple Mo. | 1.39 | .53 | 870 | 850 |
| | **West Side** | | | | |
| Block 163 | Smith | 1.20 | .39 | 790 | 810 |
| Block 158 | Linder | 1.20 | .42 | 790 | 800 |
| Block 135 | Luther | 1.20 | .58 | 660 | 660 |
| | **Northwest** | | | | |
| Block 106 | Snider | 1.15 | .33 | 820 | 820 |
| Block 62 | Bob Duryea | 1.19 | .42 | 760 | 750 |
| Block 13 | Bob Reed | 1.19 | .33 | 860 | 890 |
| | **North Side** | | | | |
| Block 18 | Chrpin | 1.22 | .24 | 970 | 970 |
| Block 64 | Perney | 1.18 | .40 | 800 | 840 |
| Block 101 | John Luethje | 1.23 | .54 | 690 | 850 |

Figure 5—A typical monthly cathodic report.

sign and construction periods in all phases of company activity.

Occasionally the Corrosion Department conducts corrosion control training schools for various groups of company personnel. These schools help greatly to stimulate interest in the general corrosion control program. The round table discussions not only bring about a better integration of corrosion control procedures with other company activity, but frequently introduce the use of new improvements.

## Work Procedure

The company was organized in 1936 and initial construction was completed that year. Fourteen months later, corrosion leaks began to appear throughout a 125-mile section of bare Dresser coupled transmission line in the Platte Valley of Nebraska. In early 1938, several cathodic protection installations were made with satisfactory results. This experience confirmed corrosion control procedures as a necessary part of the company's operation.

Since 1944, all new construction or replacement has been made by all welded steel pipe, coated and wrapped and cathodically protected at the time of construction. The original towns, and those acquired, had systems with bare welded or Dresser coupled steel pipe with varying arrays of tap saddles, pipe fittings, etc. This made protection more difficult and less economically feasible. Until a generalized policy procedure was set up, any type of service stub, service line, building entry or meter installation could be expected, depending principally on local habit.

Present procedure requires that a building entry be above ground level, with an insulating joint installed just outside the building. All service lines from the building to the property line are the customer's property and must be coated and wrapped.

The meter usually is set at the property line and is insulated from the main if the mains are not cathodically protected. If the mains are cathodically protected, the meter setting is made conductive and the service line is included in the protection scheme at no cost to the customer. A meter setting at the property line provides low pressure gas to the customer's house instead of intermediate pressure and makes meter reading more convenient. It also reduces unaccounted-for leakage, is a leverage for immediate service-line replacement if leaking, and gives free access to the meters in times of emergency. In addition it helps in distributing anodes with above-ground-lead attachment, and provides free access to lead wires for testing.

In all of the older, all bare system towns, the service lines were insulated at the building entry and at the property line. If a section of a bare town was to be protected, a service-line insulating project was set up and carried out; if no sectional protection was projected, the service-line insulating procedure then was done at the time the customer was shut-in for servicing or for meter change-out for test. At any time the customer was serviced, a complete premise survey was made for faulty appliances, faulty flues, leakage, etc.

New pipe replacements or extensions are of all welded steel, coated and wrapped. They are isolated from all bare structures, and cathodically protected by magnesium anodes at the time of construction. All new towns or additions to towns are isolated by insulating joints into sections of not more than 12,000 feet of pipe. By adopting this procedure, trouble in one part of town can be prevented from affecting the entire town. It also makes for easier location of the trouble and provides for selective treatment of an isolated section as requirements may dictate.

## Record Keeping

A complete corrosion record file of all the towns is kept in the Chief Corrosion Engineer's office. Each division manager, division corrosion technician, or local or district manager also keeps

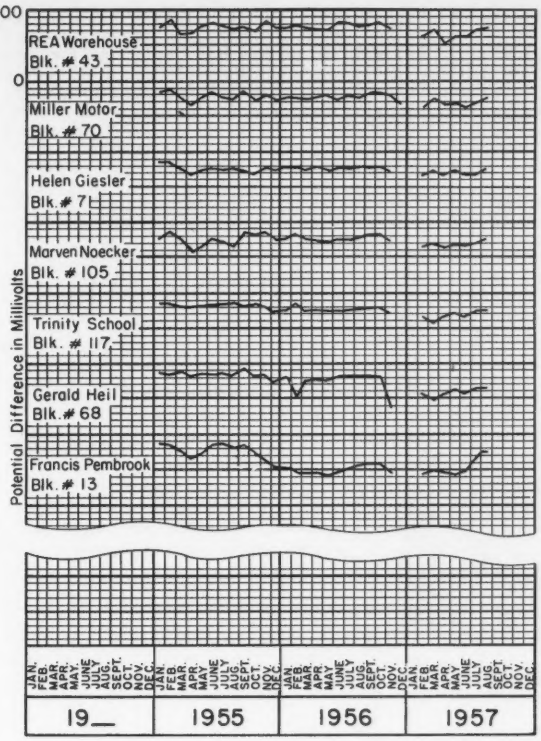


Figure 6—Monthly check report of Hartington, Nebraska.

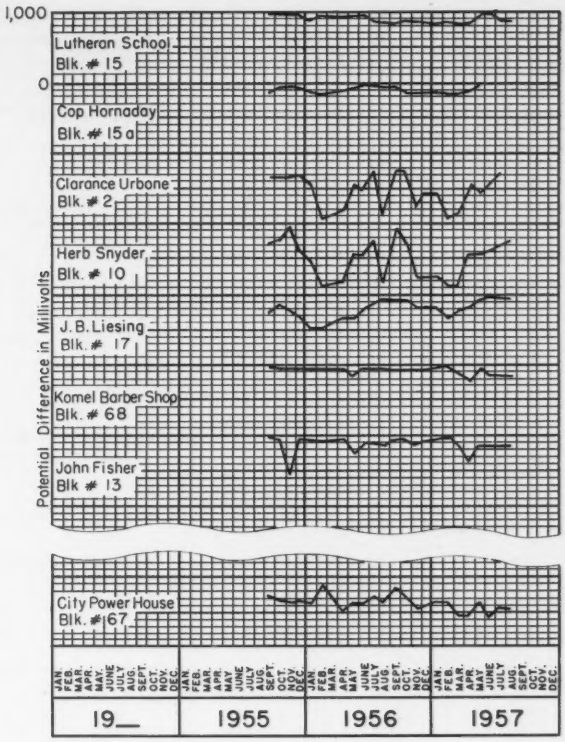


Figure 7—Monthly check report of Arapahoe, Nebraska.

a corrosion file on those towns in which he is directly interested.

Figure 1 illustrates the use of the town maps to record isolated sections, approximate anode locations and isolating joints. Each section is color-coded so as to be recognized readily. Generally, towns are piped for intermediate pressure (lbs to 10 psig) but on occasion, special loads require high pressure lines (up to 65 psig). In the larger and more highly developed business districts, low pressure (4 oz to 6 oz) systems are installed. All three may exist in some towns, but always are isolated from each other at appropriate regulator settings.

Figure 1 gives the legend of symbols used on the maps and in the block card books. Type of insulating joints, anode size, location, and date of installation are shown in some detail in the block cards.

Figure 2 illustrates the application of data to the block card record. Anode size, location, date of installation and approximate current output also are kept on file cards.

Figure 3 shows how maps of the older bare towns are used in connection with the recording of coated and wrap pipe replacements and extensions. All coated and wrapped lines are color-coded with a red line. Each protected section is color-coded as in the previous figure. By color-coding the map in this manner, one has a simple and ready reference from which to work. It is a handy form from which to determine the desirability of extending projected replacements to existing protected sections or to prevent the nuisance of small, impractical bare sections between protected sections. It may be economically feasible to replace such small sections while the crew is working nearby, and thus improve or modernize the system at relatively small additional cost.

This coding method is a handy reference in determining the desirability of adding new work to an existing protected section, or possibly to show the need for isolating the new work and starting a new treatment section. Continued addition to an isolated and protected section eventually reaches a limit and new treatment sections are desirable.

The company has set up a two-man leakage survey team in each of four divisions for the specific purpose of making leakage surveys of each town once a year. The members are provided with explosimeters, pipe locators, potentiometers and resistivity instruments; they also have been taught some of the routine uses of these instruments. Team members locate the leaks, fixing only the bad blowers or dangerous ones in a temporary manner, and report them on maps, such as shown in Figure 4. These teams determine the approximate extent of the trouble, code the leakage map, and work up a summarizing report of existing conditions.

Figure 4 presents an example of the leakage map coding. Direct cooperation of the corrosion technician, leakage team, and maintenance personnel is invaluable in arriving at practical decisions for the effective maintenance and protection of the ailing system.

After getting corrosion control installations made on a distribution system, it cannot be assumed that protection will be effective and undisturbed for a long period of time. Any number of things can happen to upset completely the successful protective scheme. For this reason constant surveillance is important. A monthly checking procedure is carried out by a local service man with the instruments that he uses in his normal service work.

A few weeks after a new system is completed and after the protection has had a chance to stabilize, a corrosion technician will make a complete survey of the new work, clearing any trouble that may exist. When the new protection is properly functioning, he will set up several test locations in each isolated section. Each month, the local service man will read and report the potential differences across the appropriate insulating joints.

Figure 5 shows the monthly check report form. The report form lists the town, date of check, the street address or name of customers at each check point, and in their proper section. When the forms are printed, the original or last annual check by the corrosion technician is included, showing the pipe-soil potential of the protected pipe, the unprotected pipe and the potential difference of the two in millivolts. The potential difference reading is made with the millivolt meter used by the reporting service man and not by a sensitive potentiometer.

If there is a short circuit or foreign contact on a protected section, the service man will note it when he makes his monthly potential difference tests. He has been taught the technique of locating such trouble, and usually gets it cleared without help. If he cannot locate the trouble, a corrosion technician will assist him. By working with the local men on these problems, the company believes it not only is promoting a stronger regard for corrosion control procedure and improving company-wide understanding, but also providing an effective training method.

With monthly potential difference

readings entered on the form, copies go to the local file, the division distribution manager, the division corrosion technician, and the Chief Corrosion Engineer.

At least once each year, the corrosion technician will make a complete check of each town in his division, making any necessary changes in reading for each test point and adding any new ones that may be appropriate. A new supply of monthly report forms also are sent out to the local offices, and the annual reports are filed.

The monthly potential difference reports, Figures 6 and 7, are recorded in a loose-leaf notebook. By keeping this record for several years, the seasonal effect on treatment, changes in current requirements, changes in anode current output, etc., are recognized in the potential trend. Any notes of interest affecting the history of the treatment may be kept on a fly sheet opposite each town record. The recording and use of the data kept in a notebook is much more convenient than if it were kept in files.

If the local people fail to send in one or more monthly check reports, a reminder card is sent out to them. In such cases it usualy is found that the tests were made but not sent in.

An effort is made to maintain at least 1.0 volt negative potential to $CuSO_4$ electrode on coated lines and at least 300 millivolt change from original potential on bare pipe. Pipe to soil potential criteria has limitations but it is a simple and useful procedure to use in check reports. In monthly checks of potential differences across a customer's insulating joint, another large structure (the water system) is used as a reference. It is recognized that while it may change, the change will not be great enough to be of practical significance if the test points have been well chosen.

**Acknowledgment**

The author wishes to thank the management of The Kansas-Nebraska Natural Gas Co., Inc. for permission to present this paper.

**Any discussions of this article not published above will appear in the June, 1959 issue**

# A New Inorganic Cement Mortar For Sulfuric Acid Service*

By ROBERT S. MERCER


## Abstract

Silicate cement mortars, consisting of a chemically inert solid filler containing a fluoride setting agent and a liquid sodium or potassium silicate binder, have been used for many years in acid-proof construction for high temperature, strong acid service. While silicate cements have performed well under unusually tough conditions, they are not without their shortcomings in sulfuric acid service. Instances of corrosive attack are explained by breakdown of the setting agent and hydrate or alum formation.

A new material of construction, a silica cement mortar, has been developed which shows promise in sulfuric acid service. The binder is a silica sol instead of a solution of a sodium or potassium silicate which is alkaline. The setting agent permits an orderly gelation of silica resulting in a strong mortar.

Unit cell dimensions are given for a number of sulfates and alums. Seven physical properties are listed and compared for sodium silicate mortar, potassium silicate mortar and silica mortar. The comprehensive strengths of these three materials after immersion in sulfuric acid are reported. 6.6.5


## Introduction

SILICATE TYPE cement mortars enjoy extensive use in chemical plant construction. The reason for this is that at normal operating temperatures such mortars are chemically resistant to all concentrations of any common acid, with the exception of hydrofluoric acid.

## Sodium Silicate Mortars

Originally, silicate mortars were mixtures of aggregate and a solution of sodium silicate. These "air setting" silicate mortars are all but obsolete today because they require curing several weeks before the construction can be put into service. The cure time depends on such factors as the air circulation, temperature, and thickness of brickwork. Specimens must cure two months or more to attain the strength of "chemical setting" silicate cement mortars which appeared in Germany about 1925.

Chemical setting silicate mortars differ from air setting mortars in that an acidifying agent, which may be an acid or which may decompose to liberate acid, is used to control and hasten the cure. Examples of setting agents are sodium fluosilicate and ethyl acetate. The formation of a silica network is responsible for the immobilization of the fluid part of the mortar and ultimately the strength and coherence of the mass. The reaction is illustrated by the following equations:

$$Na_2SiO_3 + CO_2 \rightarrow Na_2CO_3 + SiO_2 \quad (1)$$

$$Na_2SiO_3 + 2CH_3COOC_2H_5 + H_2O \rightarrow 2NaOOCCH_3 + 2C_2H_5OH + SiO_2 \quad (2)$$

$$2Na_2SiO_3 + Na_2SiF_6 \rightarrow 6NaF + 3SiO_2 \quad (3)$$

In these equations sodium metasilicate is used as the sodium silicate rather than a water glass inasmuch as water glasses have indeterminate formulas.

Reaction (1) exemplifies the air setting silicate type mortars. The carbon dioxide of the air provides sufficient acidification to cause the mortar to set up and ultimately gain sufficient strength to be useful.

Reaction (2) illustrates the use of ethyl acetate as a setting agent. Since it is a liquid, a three-component package is required. The aggregate and solution of sodium silicate is mixed, then the ethyl acetate is added. Ethyl acetate is highly flammable and has an anesthetic action, requiring isolation from flame and adequate ventilation. For this reason it is not used commercially.

Reaction (3) represents the most widely used commercial silicate mortar. It is a two-component package. The sodium fluosilicate hydrolyzes at a rate which allows sufficient time to work and apply the mortar, yet the mortar sets and hardens in a reasonable time thereafter.

Although large quantities of sodium silicate mortars have been used successfully during the past 30 years, and many installations with these mortars have held up well for 10 to 15 years of continuous service, there have been instances of corrosive attack. In most cases such attacks occurred in sulfuric acid service.

These occurrences can be attributed to two disadvantages inherent in the sodium silicate-type mortars. First, the residual sodium fluoride will form hydrofluoric acid when exposed to concentrated sulfuric acid at elevated temperatures. The mortar and the brick will be attacked by the newly-formed acid and the structure weakened.

Secondly, it will be observed in the reaction that all of the sodium present in the original sodium silicate is retained in the cured mortar. Some of it may be leached out under the conditions of use, but in actual practice it is known that most of the sodium is retained. In sulfuric acid service, sodium sulfate is formed within the pores of the mortar. This internal crystallization causes pressures sufficient to weaken or disrupt the mortar.

One way to demonstrate the damaging effect of sulfation in the laboratory is by the so-called box test (Figure 1). A box made of the mortar is filled with 20 percent sulfuric acid, and since slight leakage will occur due to the porosity, the level is maintained for the duration of the test. As sodium sulfate forms

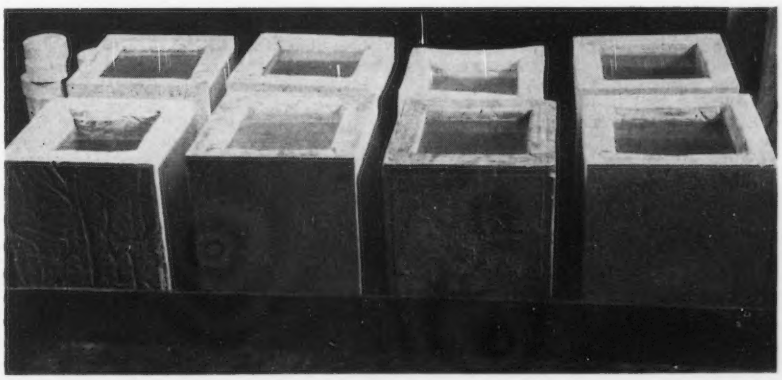

Figure 1—Box test used to demonstrate sulfation of mortar.

About the Author

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★ Submitted for publication January 13, 1958. A paper presented at the Fourteenth Annual Conference, National Association of Corrosion Engineers, San Francisco, California, March 17-21, 1958.

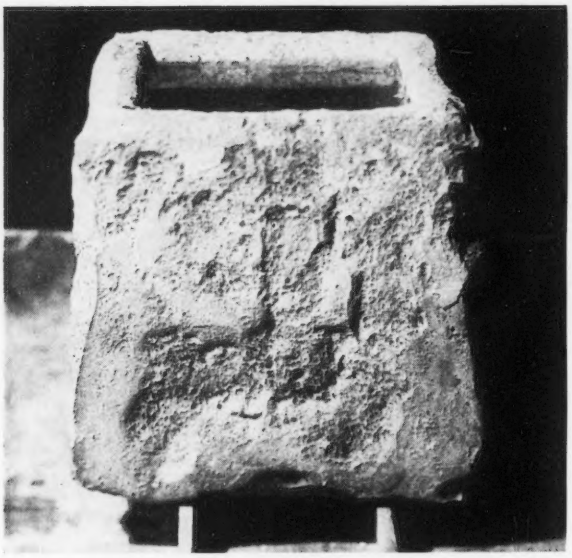

Figure 2—Sulfation of sodium silicate mortar after three-week exposure.

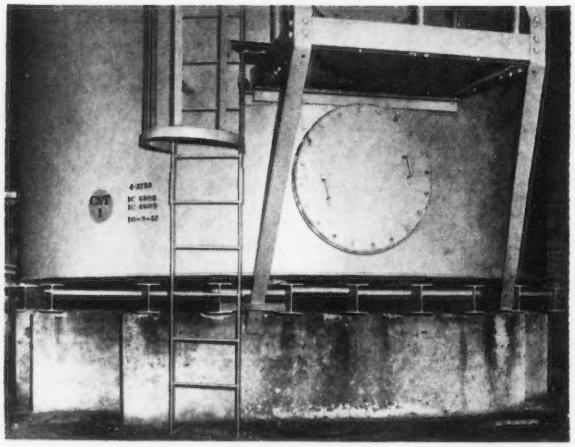

Figure 3—Steel vessel damaged by sulfation of mortar in brick lining.

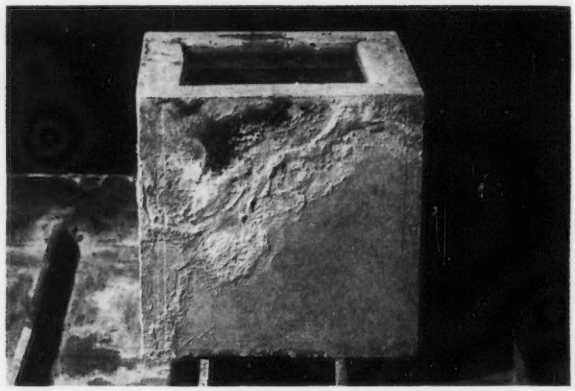

Figure 4—Potassium silicate mortar box after three-week exposure.

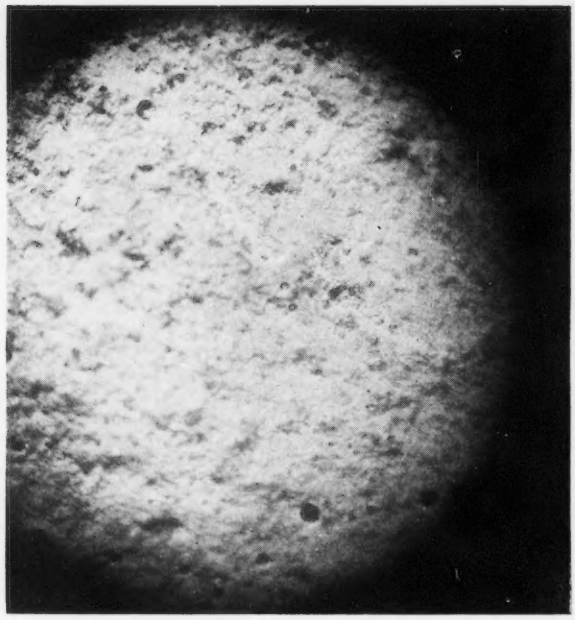

Figure 5—Alum formation in potassium silicate mortar. Original magnification, 20X; actual magnification after reduction for engraving purposes, 9X.

and hydrates, the container surface sloughs off and crumbles. Figure 2 shows a box of sodium silicate mortar after three weeks' exposure.

In commercial practice the effect of sulfation varies with the service conditions, and is manifested in different ways. The mortar might simply weaken, become soft, or might change in volume with sufficient force to buckle the steel shell as shown in Figure 3. This lead lined steel shell had a brick lining laid in sodium silicate mortar. It was used for 25 percent sulfuric acid at 175 F. The flat bottom is now dished so that the edges are raised about three inches above the supporting beams, and support is solely in the center. The mortar had expanded and weakened due to sulfation. An X-ray diffraction of the mortar showed anhydrous $Na_2SO_4$. It is not known whether expansion in this case is due to hydration, as in the case of the box test, with subsequent dehydration, or due to the formation of the anhydrous crystals.

Sodium silicate mortars used to bond masonry stack linings also have shown the formation of anhydrous $Na_2SO_4$ (V) in the area where trouble developed. In this particular case, the operating conditions were such that the hydrate would have been expected.

## Potassium Silicate Mortars

In an attempt to avoid this difficulty, potassium silicate was substituted for sodium silicate, on the theory that potassium sulfate does not form hydrates. Perhaps an alternate reason is that it apparently has a single crystalline form up to 1080 F.

Sodium sulfate has five anhydrous forms. The low temperature form (V), thenardite, inverts to monoclinic $Na_2SO_4$ (IV) at 320 to 356 F, to orthorhombic $Na_2SO_4$ (III) at 365 F, and to hexagonal $Na_2SO_4$ (I) at 465 F; on cooling it may invert to $Na_2SO_4$ (II) at 456 F.[1] Under fluctuating temperature conditions, alternate expansion and contraction at transition points might be disruptive. Little is known about the equilibrium of $Na_2SO_4$ hydrates in various concentrations of sulfuric acid at various temperatures. In water, the transition point between the anhydrous salt and the 10 hydrate (Glauber's salt) is 32.4 F for $Na_2SO_4$ and 34.5 F for $Na_2SO_4 \cdot 10H_2O$. Above this temperature, $Na_2SO_4$ always crystallizes free from water. There is also a $7H_2O$ salt which above 24.4 F converts to the anhydrous salt, while below 24.4 F passes to the 10 hydrate. It seems logical to believe that a similar situation would exist in $H_2SO_4$, only at different temperatures. Boxes made of potassium silicate mortar show no signs of sloughing, flaking, or spalling under the conditions which cause failure of sodium silicate boxes (see Figure 4).

While there are many successful installations of potassium silicate mortars, a new drawback is encountered. Sodium alums are rare, but potassium alums are easily formed. The common sulfates, $K_2SO_4$, $Na_2SO_4$, $PbSO_4$, $(NH_4)_2SO_4$, $Fe_2(SO_4)_3$ and the hydrates of $Na_2SO_4$, $Fe_2(SO_4)_3$ and $FeSO_4$, can cause trouble if crystallized in the porous mortar, but the complex salts and alums and their hydrates add to the problem. Alums are of the form $M'M'''(SO_4)_2 \cdot 12H_2O$, and more than a few combinations of

**TABLE 1—Unit Cell Dimensions of Sulfates and Alums**

| COMPOUND | Crystal | Molecules Per Unit Cell | UNIT CELL DIMENSIONS ANGSTROM UNITS | | |
|---|---|---|---|---|---|
| | | | $a_o$ | $b_o$ | $c_o$ |
| $Na_2SO_4$ (V) | Orthorhombic | 8 | 5.85 | 12.29 | 9.75 |
| $Na_2SO_4$ (III) | Orthorhombic | 4 | 5.59 | 8.93 | 6.98 |
| $Na_2SO_4$ (I) | Hexagonal | 2 | 5.38 | .... | 7.26 |
| $K_2SO_4$ (LOW) | Orthorhombic | 4 | 10.008 | 7.424 | 5.731 |
| K Al $(SO_4)_2$ | Hexagonal | 1 | 4.706 | .... | 7.960 |
| K Al $(SO_4)_2 \cdot 12H_2O$ | Cubic | 4 | 12.113 | .... | .... |
| $NH_4$ Fe $(SO_4)_2$ | Hexagonal | 1 | 4.825 | .... | 8.31 |
| $NH_4$ Fe $(SO_4)_2 \cdot 12H_2O$ | Cubic | 4 | 12.14 | .... | .... |
| $NH_4$ Al$(SO_4)_2$ | Hexagonal | 1 | 4.724 | .... | 8.225 |
| $NH_4$ Al $(SO_4)_2 \cdot 12H_2O$ | Cubic | 4 | 12.212 | .... | .... |
| Fe $SO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$ | Monoclinic | 2 | 9.28 | 12.58 | 6.22 |

**TABLE 2—Compressive Strength of Mortar After 56 Days Immersion in Acid * at 410 F**

| PROPERTY | Typical Sodium Mortar | Typical Potassium Mortar | Silica Mortar |
|---|---|---|---|
| Compressive Strength, PSI | | | |
| Before | 2230 | 2080 | 2190 |
| After | 1560 | 1240 | 6530 |
| Percent Change | —30 | —40 | +198 |

* Composition: 93 to 94 percent sulfuric acid, 1.25 percent ammonium sulfate, 1.25 percent sodium and iron sulfates. Acid was changed every 10 days.

**TABLE 3—Compressive Strength of Mortar After 28 Days Immersion in Refluxing 96 Percent Sulfuric Acid**

| PROPERTY | Typical Air Set Silicate Mortar | Typical Sodium Silicate Mortar | Typical Potassium Silicate Mortar | Silica Mortar |
|---|---|---|---|---|
| Compressive Strength, PSI: | | | | |
| Before | 3120 | 1860 | 4167 | 3560 |
| After | 990 | 1950 | 4020 | 4580 |
| Weight Loss, Percent | 6.4 | 4.4 | 4.5 | 2.0 (Gain) |

**TABLE 4—Typical Physical Properties of Silicate and Silica Mortars**

| PROPERTY | Sodium Silicate Mortar | Potassium Silicate Mortar | Silica Mortar |
|---|---|---|---|
| Tensile Strength (14 Days at 72 F), PSI | 200–300 | 300–400 | 400–500 |
| Compressive Strength (14 days at 72 F), PSI | 1400–1700 | 2000–4000 | 2500–4500 |
| Shrinkage, Percent | 2.5–3.5 | 2.5–3.5 | 2.0–3.0 |
| Bond Strength, PSI: | | | |
| To Wire Cut Brick | 135 | 155 | 100–130 |
| To Matt Brick | 60 | 270 | 100–120 |
| Apparent Porosity, Percent | 25 | 28 | 21 |
| Absorption, Percent | 16 | 17 | 10 |
| Coefficient of Thermal Expansion—— x $10^{-6}$/Degree F | 6.2 | 6.0 | 4.8 |

the monovalent (K, Na, and $NH_4$) and the tervalent (Al, Cr Fe, Co, etc) are easily formed. Examples are potassium aluminum alum ($KAl(SO_4)_2 \cdot 12H_2O$), potassium iron alum ($K\,Fe(SO_4)_2 \cdot 12H_2O$) and ammonium alum ($NH_4Al(SO_4)_2 \cdot 12H_2O$). The only common sodium alum is sodium chrome alum. Shonites $M'M''(SO_4)_2 \cdot 6H_2O$ are also formed with examples of M" being Mg, Zn, Ni, Co, and Fe. Typical would be potassium magnesium sulfate and Mohr's salt.

Unit cell dimensions of some sulfates and alums are given by Wycoff[2] and the data are tabulated in Table 1. In hexagonal systems, two unit cell dimensions are the same; in cubic systems all three are the same. Identical dimensions have not been repeated in the table.

The "unit cell" is the smallest group of atoms which can generate the entire crystal. These data are significant in indicating the structure of the crystal, and with additional crystallographic data will enable the calculation of molar volumes of various crystal states. In addition to the time factor, other factors such as temperature cycling, liquor and salt concentration, and wetting and drying, play a part in crystal growth until the crystal size is many times the unit cell dimensions. Since the primary channels or capillary systems in silica hydrogels are 5 to 10 $\mu$ in diameter (50 to 100 Angstrom units)[3] it can be seen that crystal growth can disrupt the silica gel network.

Figure 5 shows the growth of alum in a potassium silicate mortar after 28 days. The specimen was split with a chisel.

A sample of sludge taken from brickwork in sulfuric acid mist service showed by X-ray diffraction that it was essentially $KAl(SO_4)_2$. Dehydration was, of course, caused by the concentrated sulfuric acid. A spectrograph showed Fe, Al and Mg as major constituents in the mortar. It is not known whether these ions came from the brick or were impurities in the acid.

The owner of the vessel shown in Figure 3 would not have avoided trouble with a potassium silicate mortar. Specimens of potassium silicate mortar exposed in his equipment showed poor strength after immersion, and the mortar contained large crystals of iron alum, $K_2SO_4 \cdot Fe_2(SO_4)_3 \cdot 24H_2O$. The acid contained sufficient iron sulfate to rule out the use of a potassium silicate mortar.

## Silica Mortars

A new material of construction, a silica cement mortar, has been developed which shows promise in sulfuric acid service. The laboratory data are promising. While time has not permitted sufficient field testing to enable accurate predictions of service life, experience in several commercial installations indicates that many tough service conditions will be satisfactorily handled. Instead of using sodium or potassium silicate as a source of silica, the new product derives its silica network from a silica sol. The commercial sols available are of low viscosity and contain 30 to 35 percent $SiO_2$ as a colloidal suspension in water. A product which may be described as 30 percent sand in water, yet having a viscosity of 3 to 4 cps, is a curious material. Principal commercial uses are in anti-slip floor waxes, and in the textile industry.

Many attempts have been made to use silica sols to prepare mortars and cast shapes, by mixing the sol with siliceous fillers such as are used in the classical silicate mortars. Simple mixtures of sol and fillers have poor strengths after the water is removed. Strong acids, alkalies, and electrolytes cause gelation of the silica so that the mass sets rapidly without depending on dehydration, but the solid masses are very weak and usually can be crumbled in the hand. A silica gelling agent recently has been employed, which will provide strong masses, thus permitting mortars to be formulated that have higher strengths than the classical silicate mortars. Even more important, these new mortars do not have the disadvantages of the silicate mortars in sulfuric acid service.

Since the product is essentially silica, it is described as a silica mortar rather than a silicate mortar. There are no fluorides in the mortar which means that no HF can be formed in sulfuric acid service. The sodium or potassium content is reduced to a maximum of 0.7 percent expressed as $Na_2O$, or can be eliminated, depending on the formulation. Therefore, the problem of sulfate and polyvalent alum formation ceases to be a problem.

## Comparison of Silicate and Silica Mortars

One chemical company tested a typical sodium silicate mortar, potassium silicate mortar, and silica mortar in its equipment, where the silicate mortars had not given long service life. The re-

sults are tabulated in Table 2. After exposure, the alum formation within the potassium silicate mortar specimens was very pronounced. Crystals were about the size of granulated table sugar, and the loss in strength was not surprising. Actually the silica mortar had a compressive and bond strength three times that of its original. The bond strength of the silica mortar to matt surface acid-proof brick was 320 psi after exposure in contrast to 100 psi before exposure. The silica mortar was marble-like and the increase in strength is attributed to a reaction between the acid and a clay in the filler. There was no sign of alum formation in the exposed silica mortar, and certainly the strength after exposure confirms the observation.

Cylinders of various silicate mortars and a silica mortar were immersed in 96 percent sulfuric acid in the laboratory. The acid was boiled for 28 days with the results shown in Table 3. These data show the effect of sulfuric acid free of impurities. The strength of the sodium and potassium silicate mortars was not significantly changed by the test, but the silica mortar gained strength.

Some of the physical properties of the silicate and silica mortars are compared in Table 4. With the exception of bond strength, the properties of silica mortars are superior to sodium or potassium silicate mortars. Previous data given show that silica mortar has better resistance to sulfuric acid.

Tests run in boiling water, with the water changed three times per week for four weeks, show silica mortars to have half the weight loss of the best silicate mortar, and a compressive strength of 2950 psi after immersion. Most silicate cements disintegrate in this test. This does not mean however, that silica mortars would be recommended for steam or water resistances. In the case of silicate mortars, acid washing is recommended to neutralize surface alkalinity and to harden the silica network. The ASTM Recommended Practice for silicate mortars states that the acid washing should be done in two to six days after the bricks are laid. Tests have shown that acid washing of silica mortar is not necessary. The savings in time, material, and labor can be easily recognized.

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3. Wilhelm Eitel. The Physical Chemistry of the Silicates. University of Chicago Press, Chicago, Illinois, 1954.

**Any discussions of this article not published above will appear in the June, 1959 issue**

# Reinforced Plastics For Corrosion Control*

By W. A. SEVERANCE

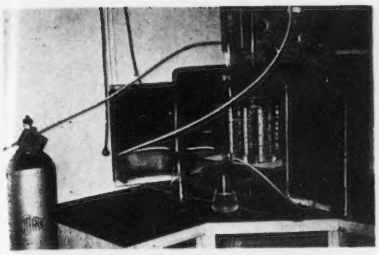

Figure 1—Chlorine exposure apparatus.

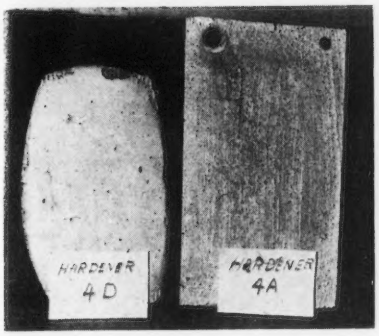


Figure 2—Comparison of epoxy hardeners.

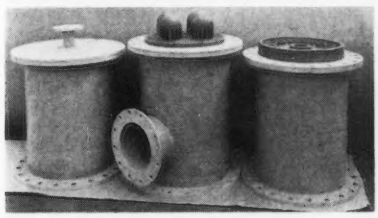

Figure 3—Reinforced polyester scrubber sections with ceramic tray and bubble caps.

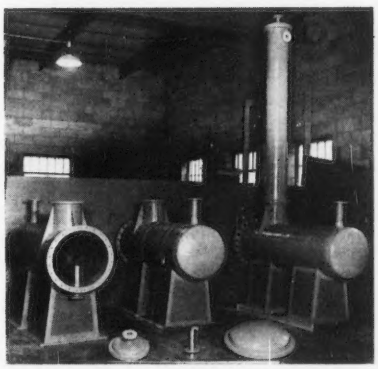

Figure 4—Reinforced polyester scrubber units.

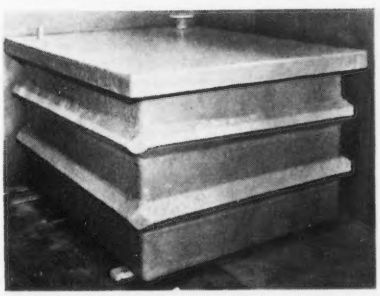

Figure 5—Reinforced polyester HCl storage tank.

## Introduction

THE WIDE range of chemical resistance of polyester and epoxy resins makes it possible to find a suitable RFP (Reinforced Plastic) for most requirements. Both resin and reinforcement must be considered in connection with chemical resistance. In most cases the resin has better chemical resistance than the glass used for reinforcement. The resins are most seriously attacked by organic chemicals, while the glass is most seriously attacked by inorganic chemicals.

The selection of resins and reinforcements requires care, especially for what might be termed "fringe" or questionable applications. The fringe applications present a real challenge to formulators of resins and laminates. Their efforts are constantly being pointed toward extending the range of usage by repeated modifying and testing. The results of this testing for the fringe applications indicate that there are wide variations in the chemical resistance of commercially available resins and reinforcements.

In comparing resins, it can be said generally that the best polyester and epoxy resins show their greatest differences in resistance to the chemical types listed in Table 1. It can be said further that polyester resins vary among themselves more than do epoxies. For example, most polyesters decompose when immersed in ethylene dichloride; to date, only one has been found to withstand it. Service with this solvent may be termed a fringe application. Other such cases are strong sulfuric acid, concentrated nitric acid and hot wet chlorine.

## Test Methods

Two types of tests have been used here to illustrate differences in chemical resistance of various resins:

1. Flexural tests (according to ASTM D-790) before and after exposure.
2. Weight change after exposure.

The limitations of flexural tests are well known. The specimens are narrow strips ½ inch to 1 inch wide, the edges of which are subject to penetrations by solutions. Even before exposure it is difficult to obtain uniform test results because of variations in the reinforcements and fabrication techniques. Thus only the broader differences are meaningful. Silica filled resins were used for the weight change tests.

## Test Results—Resins

The first fringe application considered is 70 percent sulfuric acid. Table 2 shows the results of immersion in this solution at 140 F for five days. Sample No. 1 is a resin containing a considerable amount of chlorine in its basic structure, whereas No. 10 is a general purpose resin based on ethylene glycol and maleic anhydride. Test specimens were silica filled. Obviously, the chlorine saturated molecule of resin No. 1 is an aid in combatting this strongly oxidizing condition.

For the second fringe condition the same two resins were exposed to concentrated nitric acid at ambient temperature for seven days. The weight change method was used in this test, and Table 3 shows the results. The general purpose resin decomposed shortly after the first day while the more resistant resin lost only 0.8 percent in seven days.

★ Submitted for publication January 27, 1958. A paper presented at the Fourteenth Annual Conference, National Association of Corrosion Engineers, San Francisco, California, March 17-21, 1958.

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## Abstract

Test results are shown which illustrate the versatility of reinforced plastics in solving corrosion problems. Special study has been made of resistance to solvents, organic acids, and concentrated inorganic acids, which may be termed "fringe" applications for plastics. The objective is to illustrate the differences between various polyesters and epoxies in specific chemicals.

A series of tests in wet chlorine at 210 F shows wide variations in the resistance of different brands of polyesters. Indications are that the compounds showing best resistance should be worthy of extensive field testing.

Physical test values are given for laminates used in chemical service. Laminates should be designed for maximum chemical resistance; this does not always parallel maximum strength. Factors used in engineering reinforced plastic structures also are given. Numerous photos show the variety of equipment that can be fabricated of reinforced plastics. 6.6.8

The third fringe chemical in this series is wet chlorine. A large dessicator with water in the bottom was used to expose the samples of eight different resins. Chlorine bubbled into the water, circulated around the specimens and out the top where it was absorbed in a flask of caustic soda. Change in flexural strength was used for this evaluation. Table 4 shows a wide variation in strength loss during this 14 day exposure.

Resin No. 15 is a chlorinated type and shows characteristic good resistance to this oxidizing condition. No. 4 is the same type, but from a different source. No. 12 and No. 14 are high heat distortion resins. No. 9 is a premium grade chemical resistant resin, outstanding for most uses, including chlorinated solvents and even dilute alkalies, but certainly not for chlorine. The rest are general purpose resins from different manufacturers.

The limitations of the apparatus used for this "weeding" test were recognized. In the toughest service chlorine is both wet and hot, up to 180-200 F. Therefore new equipment was designed (see Figure 1). It consists of a large pyrex jar with a neoprene cover. Chlorine bubbles constantly into water at the bottom. Samples rest on glass tubes held by a polyester laminate framework, and are sloped to shed water. Oven temperature is maintained at 210 F.

Since resin No. 15 was outstanding in the preliminary test, other chlorine containing resins were included in subsequent testing in the new equipment. Hard rubber from a Hooker cell outlet and some asbestos reinforced phenolic also were included in the testing. The phenolic is a material that has been widely used and has demonstrated good resistance to the chemical conditions. Results are shown in Table 5.

It is interesting to note that while the glass reinforced resins showed a fairly high strength loss, their final strength was still far greater than the original strength of the phenolic. It is recognized that these tests are not conclusive and probably do not come close to copying actual conditions. They do, however, point out which resins should be considered for field testing. At this time resin No. 2 is in service in a Hooker type cell top, as well as other components of chlorine collection and distribution systems.

A fourth fringe application involves a silica filled, glass reinforced epoxy resin. Among epoxies there are resin variations, but they are not as outstanding as with the polyesters. Wider variations may be found in their curing agents. It has been said that "the technology of epoxy resins is actually the technology of curing agents". This may be partially illustrated in Figure 2, which shows two panels exposed to a boiling solution containing dilute sulfuric acid, acetone and terpenes. Curing agent 4D differs from 4A in that it contains a percentage of another curing agent added for flow control. It is obvious that the 4A exhibits the best chemical resistance.

A final illustration also involves epoxies with different curing agents. Table 6 shows results of boiling two epoxy systems in 25 percent nitric acid. Sample A was cured with Shell Curing Agent Z, while sample B was cured with an undisclosed compound. The failure of sample A was not a surprise since epoxies are usually very sensitive to nitric acid. To have sample B remain in one piece for a week was certainly startling.

### Test Results—Reinforcements

Variations in the chemical resistance of resins have been discussed. The second consideration is the variation in both chemical resistance and physical properties attributed to reinforcing fibers. The fibers most commonly used are random glass mat and woven glass fabrics. Less commonly used are asbestos, and synthetics, such as Orlon, Dacron and Dynel.

Glass mat is probably the least expensive and most widely used form of glass reinforcing. With hand lay-up methods a glass content between 20 percent and 28 percent may be obtained. Physical strength is relatively low compared with higher glass contents resulting from pressure laminating. Within limits, physical strength is directly proportional to the glass content. In some cases chemical resistance may be considered inversely proportional to glass content.

Woven glass fabrics come in many weights, from fine mosquito netting size up to very heavy basket weaves weighing as much as 27 ounces per square yard. The latter, called woven rovings, are used alone and combined with mat to produce stronger laminates. Contact laminates of roving cloth may contain as high as 50 percent glass.

Another fabric, not widely used, but of some academic interest, is chemical staple glass cloth. This has a short fibre which does not contribute high strength like the commonly used types. It is of interest for equipment fabrication because of its superior chemical resistance.

Asbestos fibers have been used for many years in some types of acid proof equipment. Only recently have they been put into forms that can be used in the same way as glass, in making laminates. The best natural fiber for chemical equipment is African Blue Asbestos.

The synthetic fabrics are not generally used alone because their laminates do not have high strength. They are used as thin veils or barriers 10-30 mils in thickness when saturated, on the surface of laminates to protect the glass from chemical attack. They also contribute increased abrasion resistance.

Table 7 shows fiber contents and physical properties of the above mentioned reinforcements fabricated by hand lay-up methods. Certainly the strength of the last three items, chemical glass, asbestos mat and Orlon, would not encourage their use in laminating without help from the stronger glass fibers. Test work is now in progress evaluating possible applications for the asbestos, but nothing specific can be said at this time. However, the advantage of using chemical glass in certain applications has been aptly demonstrated. One demonstration is shown in Table 8. Two epoxy laminates were prepared, one reinforced with woven roving, the other with chemical glass. They were immersed in concentrated hydrochloric acid for 6 months, then tested for flexural strength. The superiority of the chemical glass is obvious.

Orlon, Dacron and Dynel are used as barriers most frequently in fluoride service. A startling illustration of the use of Orlon fabric to protect glass reinforcing in this service is seen in a recent test. A section of glass reinforced polyester

**TABLE 1—Comparison of Chemical Resistance—Polyesters vs Epoxies**

| Corrosion Medium | Polyesters | Epoxies |
|---|---|---|
| Oxidizing acids | Good | Conditional |
| Alkalies | Conditional | Good |
| Chlorinated solvents | Good | Conditional |
| Ketones | Poor | Good |
| Organic acids | Good | Conditional |

**TABLE 2—Resistance to Sulfuric Acid**

| Resin No. | Percent Acid | FLEXURAL STRENGTH Original, PSI | Final, PSI | Percent Change |
|---|---|---|---|---|
| 10 | 70 | 5,820 | 1,300 | —77 |
| 1 | 70 | 4,550 | 4,470 | — 2 |

Reagent: Sulfuric acid 70 percent (Immersion)
Temperature: 140 F
Time: 5 days
Cure: Post cure—2 hrs at 180 F

**TABLE 3—Resistance to Nitric Acid**

| Resin No. | PERCENT CHANGE 1 Day | 4 Days | 7 Days |
|---|---|---|---|
| 10 | —1.70 | Decomposed | . . . |
| 1 | —0.20 | —0.70 | —0.80 |

Reagent: Nitric acid 73 percent
Time: 7 days
Temperature: Ambient

**TABLE 4—Resistance to Chlorine**

| Resin No. | FLEXURAL STRENGTH Original, PSI | Final, PSI | Percent Change |
|---|---|---|---|
| 11 | 24,395 | 21,374 | —12.3 |
| 12 | 21,782 | 11,640 | —46.8 |
| 13 | 25,699 | 21,682 | —15.6 |
| 14 | 19,160 | 16,969 | —14.2 |
| 9 | 20,019 | 11,907 | —40.4 |
| 3 | 23,492 | 19,095 | —18.8 |
| 4 | 16,017 | 11,887 | —25.7 |
| 15 | 24,832 | 23,723 | — 4.5 |

Reagent: Wet $Cl_2$
Time: 14 days
Temperature: 80—90 F

**TABLE 5—Comparison of Polyesters and Other Materials in Hot Chlorine**

| Resin No. | FLEXURAL STRENGTH Original, PSI | Final, PSI | Percent Change |
|---|---|---|---|
| 1 | 18,660 | 14,430 | —22.6 |
| 2 | 19,600 | 16,300 | —16.9 |
| 15 | 16,397 | 11,378 | —30.6 |
| Hard Rubber | 8,230 | 6,170 | —25.1 |
| Asbestos Phenolic | 4,303 | 4,083 | — 5.1 |

Reagent: Wet $Cl_2$
Temperature: 210 F
Time: 14 days

**TABLE 6—Resistance of Epoxies to Nitric Acid**

| Sample No. | Curing Agent | WEIGHT CHANGE PERCENT 24 hrs | 72 hrs | 140 hrs |
|---|---|---|---|---|
| A | Shell Z | Failure | | |
| B | Undisclosed | | +1.12 | —2.58 |

Reagent: 25 percent nitric acid
Temperature: Boiling
Time: 140 hours
Cure Time: 3 hrs at 300 F

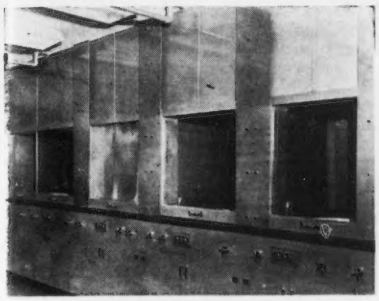

Figure 6—Reinforced polyester laboratory fume hood and bench tops.

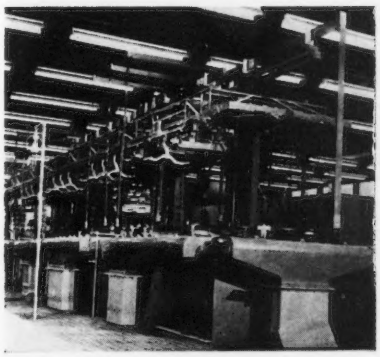

Figure 7—Reinforced polyester down draft fume hoods.

**TABLE 7—Physical Properties of Polyester Resins With Various Reinforcements**

| Fiber Type | Percent Fiber | PSI Flexural Strength | PSI Tensile Strength |
|---|---|---|---|
| Mat | 28 | 19,000 | 9,237 |
| Roving Cloth | 57 | 48,450 | 35,200 |
| Mat and Roving Cloth | 30 | 22,000 | 12,410 |
| Chemical Glass | 28 | 8,764 | 4,541 |
| Asbestos Mat | 40 | 6,203 | 2,313 |
| Orlon | 17 | 8,600 | 2,814 |

pipe, faced on the inside with Orlon, has been serving as a vessel for concentrated hydrofluoric acid (52 percent) for several months.

There is another factor that must be considered in designing laminates for chemical service. The statement was made earlier that resins have better resistance to inorganic chemicals than glass fibers. This fact was demonstrated during a test in the chlorine apparatus. Laminates of Resin No. 2 were prepared with different fiber contents. Table 9 shows the details of this test, in which sample A with its higher glass content showed a greater attack than sample B with low glass content.

It has been shown that there are wide variations in the chemical resistance of various polyesters, epoxies and hardening agents. The differences in the physical and chemical properties of different reinforcements also have been illustrated. Additionally there are polyester resins that have high heat distortion points, and an important group that will not support combustion. The properties of epoxy resins can be varied widely from rubber-like solids to highly infusible solids which withstand temperatures up to 500 F.

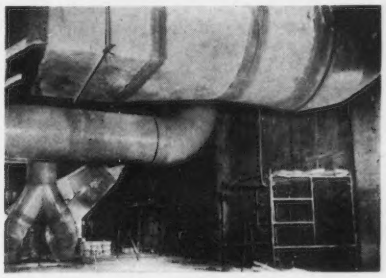

Figure 8—Reinforced polyester duct work for plating fumes.

**TABLE 8—Comparison of Chemical and Regular Glass**

| Type of Glass | FLEXURAL STRENGTH | | |
|---|---|---|---|
| | Original, PSI | Final, PSI | Percent Change |
| Chemical | 11,800 | 10,300 | —12 |
| Regular | 25,000 | 13,300 | —47 |

Reagent: Concentrated hydrochloric acid
Time: 6 months
Temperature: Ambient

## Reinforced Plastic Tank Linings

Much work has been done in the reinforced plastics field using a steel or concrete supporting member for polyester or epoxy base trowelling compounds which are reinforced with glass or synthetic fabrics. The designer may greatly extend the usefulness of reinforced plastics by using these combinations. Applications involving greater stresses at higher temperatures and greater mechanical abuse may be handled with these materials. For example, an epoxy base trowelling composition reinforced with woven cloth on a steel tank may be used as a pressure vessel at temperatures well beyond the capabilities of unsupported reinforced plastics.

## Engineering With Reinforced Plastics

Bringing all factors together into a finished product that will meet the requirements of a given application is a task for the design engineer. He first must know the actual chemical resistance of the resin. Next he must know the original physical properties of various combinations of resin and reinforcements. Thirdly, he must know the effect of the chemical environment on these physical properties. Fourthly, he must know the effect of service temperatures on physical properties. From these factors he must calculate the thickness and construction of laminate required to overcome losses due to environment and still leave sufficient physical strength. He must consider stress points and provide means of strengthening.

Designing in RFP is not as straightforward as designing in metals. There are many inconsistencies in reinforcements and in fabrication techniques that result in rather wide strength variations. To compensate for these inconsistencies, RFP equipment sometimes may be overdesigned. For example, in designing a tank, strength losses may be expected from water and chemical exposure and from heat. Inconsistencies in reinforcements and fabrication may result in deviations from the average strength. To correct for these and other possibilities it is common practice to use as low as one-half the physical strength values in developing practical wall thickness.

Figure 9—Filled and reinforced epoxy lining on fume exhaust fan.

Figure 10—Filled and reinforced epoxy lined tank cover.

**TABLE 9—Effect of Glass Content**

| Sample No. | Glass Content | FLEXURAL STRENGTH | | |
|---|---|---|---|---|
| | | Original, PSI | Final, PSI | Percent Change |
| A | 21% | 19,600 | 16,300 | —16.9 |
| B | 15% | 10,126 | 9,356 | — 7.6 |

Reagent: Wet $Cl_2$
Temperature: 210 F
Time: 14 days
Resin: No. 2
Reinforcement: Glass mat

## Illustrations

Some of the variety of shapes that may be fabricated are shown in the following illustrations. Except for Figures 9 and 10, these are reinforced polyester structures.

Figure 3 shows sections of a scrubber with ceramic tray and bubble caps. This equipment was used to scrub gases containing chlorine.

Figure 4 shows three complete unit scrubbers which consist of a packed tower and reservoir. Gases containing hydrochloric acid and chlorine at temperatures up to 350 F enter the small inlet at the closed end of the tank, are cooled by contact with solution in tank, and pass up through the packed tower. A dilute soda ash solution removes the corrosives.

Figure 5 is a rectangular tank and cover used for storing dilute HCl.

Figure 6 shows a laboratory fume hood constructed of polyester resins, including the bench top, front, inside walls, and fume ducts. The bench top is a laminate faced with carbon-filled resin, which may be rubbed to a glossy surface resembling blackened alberene stone.

Figures 7 and 8 show parts of the fume removal system of a large plating installation. Figure 7 shows the downdraft hoods and Figure 8 parts of the collecting ductwork. This ductwork is in varying diameters up to 64 inches.

Figure 9 is a fan for exhausting fumes from an anodizing system. It is lined with a ⅛ inch thickness of filled and reinforced epoxy.

Figure 10 shows a tank cover lined with a 3/16 inch thickness of filled and reinforced epoxy. The tank was also lined. The service was dilute sulfuric acid, containing carbon bisulfide, at temperatures up to 190 F.

## Conclusion

The scope of chemical resistant applications for supported and unsupported reinforced plastic structures covers a wide range of operating conditions in the chemical processing, metal finishing, food processing and related industries. By proper selection of laminate or lining the design engineer is practically without limitation as to size of unit that can be fabricated. Strengths are attainable to cover the majority of industrial applications.

As research continues, an increasing scope of chemical resistance and temperature resistance is expected to widen further the range of properties of these materials.

**Any discussions of this article not published above will appear in the June, 1959 issue**

## DISCUSSIONS ON TECHNICAL ARTICLES ARE SOLICITED

Dicussions on technical articles published in Corrosion will be accepted for review without invitation. Discussions must be constructive, accompanied by full substantiation of fact in the form of tables, graphs or other representative data and be submitted in three typewritten copies.

Authors of discussions are asked to supply one copy of figures suitable for reproduction and will be sent on request a copy of the NACE Outline for the Preparation and Presentation of Papers.

Discussions will be reviewed by the editor of Corrosion and will be sent to the author of the paper discussed for his replies, if any. Publication will be in the Technical Section with full credit to the authors together with replies. Discussions to papers presented at meetings of the association may be submitted in writing at the time of presentation or later by mail to the editorial offices of Corrosion, 1061 M & M Bldg., Houston 2, Texas.

# Processes of Electrochemical Corrosion*

By G. V. AKIMOV


## Abstract

Theoretical considerations involved in determining the potential of hydrogen and oxygen electrodes are reviewed briefly. Overvoltage is discussed in detail. The various connected stages involved in the process of the passage of ions into solution are outlined.

Use is made of the Evans diagram for real processes. In making the study of processes with hydrogen depolarization it was found convenient to use a model of a microelement. A comparison of experimental data obtained with models and from deductions from the Evans diagrams indicates that there was a complete agreement between the theory and experiment for processes with hydrogen depolarization.

Considerable attention was given to the factors affecting the rate of oxygen diffusion to the metal in view of the fact that the rate of corrosion processes with oxygen depolarization is determined mostly by the rate of oxygen diffusion toward the metal surface. A model was used to examine the part played by the electrical resistance of a cell with oxygen depolarization. It was found that it was only when the resistance became very large and the potential difference was close to the initial value that the current started to decrease. Experiments showed also that changing the anodic material did not influence the rate of the cathodic process when it was controlled by the rate of oxygen diffusion to the cathode.

The theory of microcells is examined in detail and a review made of some of the experimental data for processes with hydrogen depolarization. The influence of alloying elements on corrosion rates of metals in various media is discussed. A number of explanations are offered to show why the regularities observed on models are not applicable to corrosion of microelements.

The "difference effect" is discussed in connection with corrosion processes having hydrogen depolarization. Other topics considered include electrochemical cells with differential aeration, corrosion processes in a moisture film, and atmospheric corrosion. Extensive data are reported in 54 figures and 6 tables. **3.6.8**


## Introduction

THIS CHAPTER will deal with a number of processes of electrochemical corrosion. Before the processes of interest are considered, however, it would be well to review some statements from the theory of hydrogen and oxygen electrodes, and the theory of overvoltage.

## Potential of Hydrogen and Oxygen Electrodes

The potential of a hydrogen electrode is determined by kinetic equilibrium at the electrodes:

$$H_2 \rightleftarrows H + H,$$

$$H + H_2O \rightleftarrows H^+ \cdot H_2O + e$$

The potential of a hydrogen electrode depends both on the hydrogen ion concentration ($C_{H^+}$) in solution, and on the pressure of the hydrogen gas ($P_{H_2}$) saturating the passive electrode which usually is platinized platinum.

According to the Nernst equilibrium equation, the hydrogen potential can be expressed by

$$E_H = \text{const} + \frac{RT}{F} \operatorname{Ln} \frac{C_{H^+} \cdot fH^+}{\sqrt{P_{H_2}}} \qquad (45)$$

with $C_{H^+}$ equal to the hydrogen ion concentration, $fH^+$ representing the hydrogen activity at given conditions, and $P_{H_2}$ indicating the hydrogen gas pressure. Assuming $E_H = o$ for $C_{H^+} \cdot fH^+ = 1$ and $P_{H^+} = 1$ atm, and assuming furthermore that $fH^+$ is approximately 1 in diluted solutions, the equation becomes

$$E_H = \frac{RT}{F} \operatorname{Ln} \frac{C_{H^+}}{\sqrt{P_{H_2}}} \qquad (46)$$

Figure 105 shows the dependence of hydrogen potential on pH for various hydrogen gas pressures. rH is the negative Brigg's logarithm of the hydrogen pressure: $P_{H_2} = 10^{-rH}$.

The potential of an oxygen electrode is given by the equilibrium at the electrode:

$$O_2 \rightleftarrows O + O$$

$$O + 2e \rightleftarrows O^{--}$$

$$O^{--} + H_2O \rightleftarrows 2\,OH^-$$

For a perfectly reversible electrode (not realizable in practice), the Nernst equation is

$$E_o = \text{const} + \frac{RT}{nF} \operatorname{Ln} C_{H^+} + \frac{RT}{4F} \operatorname{Ln} P_{O_2}, \qquad (47)$$

where $P_{O_2}$ is the pressure of oxygen gas surrounding the passive electrode.

For simplicity, it will be assumed again that the activity of hydrogen ions is unity.

It has been calculated that for normal conditions ($C_{H^+} = 1$, $P_{O_2} = 1$ and 25°) the potential of a reversible hydrogen electrode is +1.229 V. Therefore

$$E_o = 1.229 + \frac{RT}{nF} \operatorname{Ln} C_{H^+} + \frac{RT}{4F} \operatorname{Ln} P_{O_2}. \qquad (48)$$

The values of the second and third terms of the Equation (48) are negative when the hydrogen ion concentration is less than unity and the oxygen pressure is less than 1 atm.

The dependence of the oxygen potential on pH and on the hydrogen gas pressure $P_{O_2}$ also is given in Figure 105. rO indicates the negative powers of oxygen pressure. It should be noted that lowering hydrogen gas pressure increases the hydrogen electrode potential, whereas lowering oxygen gas pressure decreases the oxygen electrode potential.

The straight line for $rH = 27$ in Figure 105 corresponds to the hydrogen (or oxygen) potential for water in the absence of dissolved hydrogen and oxygen. In this case, hydrogen and oxygen in water can be formed only through thermal dissociation of water:

$$2H_2O \rightleftarrows 2H_2 + O_2$$

The dissociation constant of this reaction at room temperature is very small, and the dissociation pressure corresponds to about $10^{-27}$ atm for hydrogen and 0.5 ($10^{-27}$) atm for oxygen at 25C. The rH values higher than 27 (or the rO values lower than 27) indicate some predominance of oxidizing power of the solution, whereas $rH < 27$ (or $rO > 27$) belong to solutions in which reduction prevails. Thus, it is possible to express quantitatively by means of rH (or rO), the oxidation-reduction characteristics of a solution, relative to pure water, free of oxygen and hydrogen.

It will be seen that both the hydrogen and oxygen electrodes form an oxidation-reduction system:

$$\underset{\text{Red}}{H} \rightleftarrows \underset{\text{Ox}}{H^+} + e,$$

$$\underset{\text{Red}}{2\,OH^-} \rightleftarrows \underset{\text{Ox}}{O} + H_2O + 2e.$$

The values of rH, or rO can be used for a quantitative expression of the oxidation-reduction properties of a given oxidation-reduction system.

## 2. Overvoltage[1, 2, 3, 4, 5, 11, 19]

A finite rate of any electrochemical process can be achieved only when there is a finite deviation from the state of equilibrium. Assume for example, that there is an equilibrium between the hydrogen ions and molecules at the passive platinum electrode:

$$2H^+ \cdot H_2O + 2e \rightleftarrows H_2 + 2H_2O,$$

which corresponds to above discussed equilibrium at the hydrogen electrode. In the state of equilibrium, the rate of neutralization of hydrogen ions and that of the reverse process—the formation of

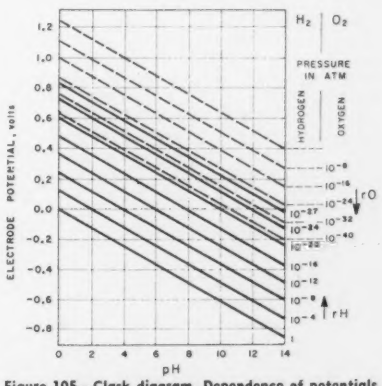


**Figure 105—Clark diagram. Dependence of potentials of hydrogen and oxygen electrodes on pH for various pressures of oxygen and hydrogen (Clark).**

★ Chapter 4 of the book "Theory and Research Methods of Metallic Corrosion," published originally by the Publishing House of the Academy of Science, U.S.S.R., Moscow, 1945. This translation was prepared by S. S. Levy and R. B. Mears both of the Applied Research Laboratory, U. S. Steel Corporation.

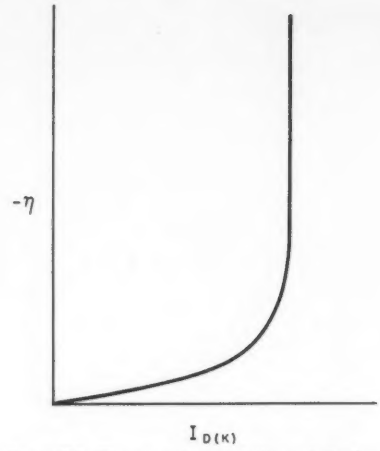


Figure 106—The curve of concentration polarization.

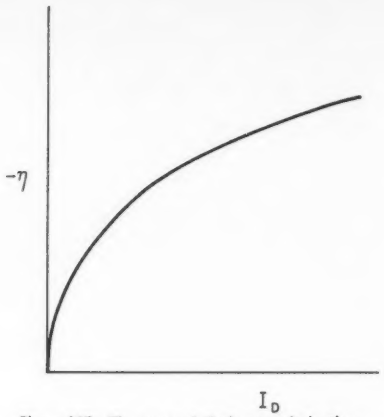


Figure 107—The curve of discharge polarization.

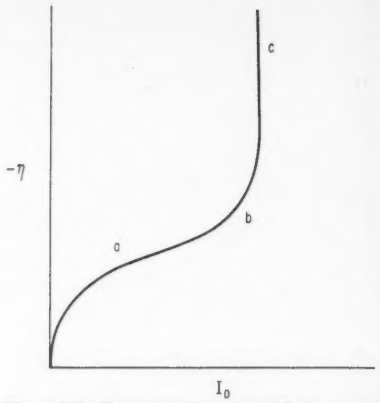


Figure 108—The curve of a mixed (discharge and concentration) polarization.

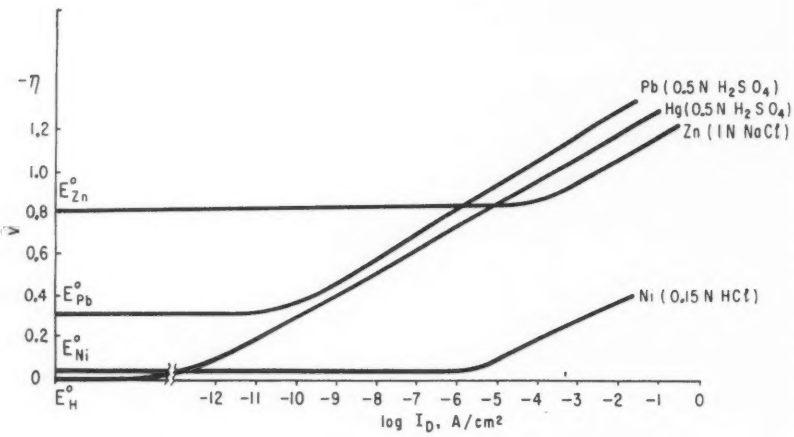


Figure 109—The relation between current density and overvoltage.

ions—are equal. Clearly, there will be no current through the platinum electrode.

To every state of equilibrium there is a corresponding potential of the hydrogen electrode, which depends essentially upon the hydrogen ion concentration and upon the hydrogen gas pressure.

Equilibrium is disturbed when a platinum electrode is polarized by creating a potential difference. When the polarization is cathodic, the rate of discharge of hydrogen ions is greater than the reverse reaction (i.e., the formation of hydrogen ions). Hydrogen gas is formed at the electrode and the solution in the vicinity of the electrode becomes more basic because of the consumption of hydrogen ions of the electrolyte. When the polarization is anodic, the formation of hydrogen ions proceeds more rapidly than the discharge of ions, with the resulting increase of acidity of the solution at the electrode and consumption of hydrogen gas. In both cases, there will be a current through the electrode corresponding to the rate of the process at the electrode (i.e., the formation of hydrogen, when the polarization is cathodic, and the formation of hydrogen ions, when the polarization is anodic). Instead of the equilibrium potential, there will be another value for potential, corresponding to the new, unbalanced condition at the electrode.

For an active electrode in a solution containing its own ions, there will be a similar equilibrium

$$[M^+ \cdot e]_s + [n\,H_2O]_1 \rightleftarrows [M^+ \cdot n\,H_2O]_1 + e_s$$

(where s indicates the solid metal phase and 1 — the liquid phase), and there will be a certain electrode potential $E_{M_0}$. When the polarization is cathodic, there will be a metal deposition on metal, because the discharge of ions will prevail over the transfer of ions into solution. With anodic polarization, however, the rate of ion formation in the solution is greater than the rate of the reverse process of discharge of ions. The resulting process will again correspond to the current through the electrode, and the electrode potential will have new values, according to the deviation from the state of equilibrium.

When the process takes place easily, that is, with a low resistance, even a small deviation from the state of equilibrium in a given direction causes a considerable predominance of the corresponding process over the reverse process. In other words, even a small deviation from equilibrium will produce a pronounced rate of a resulting process. However, when the resistance to the process is high, a noticeable rate of the resulting process can be achieved only when the deviation from the equilibrium is large. This applies to both the anodic and the cathodic polarizations. If, for instance, the transfer of ions from the metal into solution proceeds easily, then even a small deviation from the state of equilibrium will cause a high rate of passing of ions into solution.

The difference between the potential of an electrode conducting a current, and that of the same electrode in equilibrium conditions (without current) is called overvoltage. Thus, the overvoltage is a measure of the deviation of the electrode process from the state of equilibrium.

The apparently simple process of the passage of ions into solution is in reality a complex one, consisting of several connected stages. The summary process

$$[M^+ \cdot e]_s + [n\,H_2O]_1 \rightleftarrows [M^+ \cdot n\,H_2O]_1 + e_s$$

can be divided in at least two stages.

1. (a) Metal is dissolved: hydration of ion and removal of an electron
   (b) Metal is deposited: discharge and dehydration of the ion
2. (a) Metal is dissolved: diffusion of the hydrated ion from the metal surface into the solution
   (b) Metal is deposited: diffusion of the hydrated ion from the solution toward the metal surface

$$[M^+ \cdot n\,H_2O]_1 \rightleftarrows [M^+ \cdot n\,H_2O]_1$$

Surface of the electrode — Solution

In the case of the cathodic deposition of metal, beside these two stages, a third one has to be added:

$$[M^+ \cdot e]_s \leftarrow [M^+ \cdot e]_s$$

The whole surface of metal — Incompletely built section of the metal lattice

The latter process is surface diffusion of metal atoms deposited on the surface, toward the sections of the metal lattice which are not yet completely built up. The necessity of introducing this third stage of the process is indicated by some regularities of electrolytic deposition of metal crystals.

The general process for the hydrogen electrode

$$2H^+ \cdot H_2O + 2e \rightleftarrows H_2 + 2H_2O$$

consists of at least four successive processes.

1. With cathodic polarization, the passing of hydrogen ions from the solution to the electrode surface:

$$[H^+ \cdot H_2O]_1 \rightleftarrows [H^+ \cdot H_2O]_1$$

The bulk of solution — Electrode boundary

2. Discharge of the ion and adsorption of the hydrogen atom by the metal surface:

$$[H^+ \cdot H_2O]_1 + e_s \rightleftarrows [H]_s + [H_2O]_1$$

3. Formation of a hydrogen molecule from the atoms at the metal surface:

$$[2H]_s \rightleftarrows [H_2]_s$$

4. Desorption of hydrogen molecules and formation of hydrogen bubbles:

$$[H_2]_s \rightleftarrows [H_2]_g$$

Molecules adsorbed by the surface — Gas bubbles

If the whole process is in a state of equilibrium, all parts of the process must also be in the state of equilibrium. Thus, the rates of any of the connected processes (from left to right and vice versa) must be equal.

Now, if by means of a potential difference the electrode is polarized and the whole process is removed from the state of equilibrium, what happens to the individual successive processes? Each of the successive reactions has its own resistance; hence the parts played by the individual processes when the state of equilibrium of the whole process is disturbed, are not the same. Those partial processes which have a low resistance and need only a small deviation from the state of equilibrium to proceed with considerable rates, will be less important than those proceeding with difficulty (with large resistance). If in the chain of the successive processes, one of them has a much larger resistance (and therefore a much smaller rate at equal deviations from equilibrium) than the others, then it can be said in many cases that this particular process determines the deviation from the state of equilibrium of the whole process and controls the rate of the latter.

As mentioned above, the deviation of the potential from its equilibrium value (that is, the overvoltage) when there is some process at the electrode having a finite rate, is some measure of this rate. If the functional dependence between the rate of the process which is proportional to current through the electrode and the overvoltage is known, then the rate of the process at the electrode can be determined from the value of the overvoltage.

The form of the function may change from case to case depending on the partial reaction controlling the rate of the whole process. Assume, for instance, that the flow of hydrogen ions toward the surface of a cathode during cathodic evolution of hydrogen (reaction 1) is the slowest step in the series of processes. For simplicity, assume that the hydrogen ion concentration in the solution is not very high, and that there is an excess of external electrolyte, so that the current is carried by the ions of this electrolyte, whereas the hydrogen ions are moving toward the cathode only because of diffusion.

The diffusion coefficient for hydrogen ions under these conditions is denoted by $D_{H^+}$. Diffusion takes place essentially in a thin layer of solution of the $\delta$ thickness (more about this will be said later); outside of this layer the transfer of ions is accomplished by convection. Let $C_{H^+}$ (liquid) be the hydrogen ion concentration in the solution, and $C_{H^+}$ (cathode) be that at the cathode boundary. Then, according to the usual equation of diffusion,

$$V_{H_2} \cdot F = \frac{I_k}{S} = I_{D(k)} = F \cdot D_{H^+} \cdot \frac{C_{H^+}\ (\text{liquid}) - C_{H^+}\ (\text{cathode})}{\delta} \quad (49)$$

$V_{H_2}$ is the rate of hydrogen evolution at the cathode of 1 cm² area, F is the Faraday constant, S is the area of the electrode in square centimeters, $I_k$ is the current through the cathode, and $I_{D(k)}$ is the cathodic current density.

The overvoltage $\eta = E_K - E^o_K$ is in this case, according to the Nernst equation

$$\eta = \frac{RT}{F} \cdot \text{Ln} \frac{C_{H^+}\ (\text{cathode})}{C_{H^+}\ (\text{solution})} \quad (50)$$

It should be noted that for cathodic polarization the sign of $\eta$ is negative.

From Equation (50)

$$\text{Ln} \frac{C_{H^+}\ (\text{cathode})}{C_{H^+}\ (\text{solution})} = \frac{\eta F}{RT};$$

$$\exp \frac{\eta F}{RT} \cdot C_{H^+}\ (\text{solution}) = C_{H^+}\ (\text{cathode}) \quad (51)$$

Substituting (51) in (49), the following equation is obtained:

$$V_{H_2} \cdot F = \frac{I_k}{S} = I_{D(k)} = \frac{F \cdot D_{H^+}}{\delta} \cdot C_{H^+}\ (\text{liquid}) \cdot \left(1 - \exp \frac{F}{RT}\right) \quad (52)$$

For large deviations from the state of equilibrium, when $|\eta| > \frac{RT}{F}$, the term $\exp \frac{\eta F}{RT}$ is very small ($\eta$ is negative), and $I_{D(k)}$ becomes a constant $= \frac{F \cdot D_{H^+}}{\delta} \cdot C_{H^+}$ (liquid).

Thus, the cathodic current density approaches a limiting value when the overvoltage is increasing. Figure 106 illustrates the dependence between $I_{D(k)}$ and $\eta$, that is the cathodic polarization curve for the concentration polarization. The overvoltage in this case can be called "concentration overvoltage."

In an acid solution not containing an extraneous electrolyte, the process is more complicated, because the ions of the acid carry the current. The hydrogen ions move not only because of diffusion, but also because of the electric field. The relation between the current density and the overvoltage is given then by

$$I_{D(k)} = \frac{E \cdot D'_{H^+}}{\delta \cdot v_x} C_{HX} \cdot \left(1 - \exp \frac{\eta F}{kT}\right), \quad (53)$$

with $D'_{H^+}$ as the diffusion constant for hydrogen ions in the solution of pure acid, $C_{HX}$ as the concentration of the acid HX, and $v_x$ as the anion mobility. If the rate of the evolution of hydrogen is determined by the partial reaction of discharge of ions (reaction 2), then the curve has a different shape. Erdey-Grutz and Volmer have shown that in this case the rate of the process can be expressed by

$$I_D = F \cdot K_1 \left[\exp\left(\frac{\alpha \cdot \eta F}{RT}\right) - \exp\left(+\frac{(1-\alpha)\,\eta \cdot F}{RT}\right)\right], \quad (54)$$

where K, a constant essentially given by composition of the solution, $\alpha$ has a value between 0 and 1 (the value found empirically is ½ while the theoretical calculation has been given by Gurney). Figure 107 shows the curve expressed by (54)

The meaning of (54) becomes clearer when it is recalled that the rate of a chemical reaction depends in general on the activation energy Q in the following manner:

$$V = K \exp\left(-\frac{Q}{RT}\right)$$

The cathodic polarization (the cathode acquiring a higher negative potential,

**TABLE 6—Electrode Potentials, Overvoltage of Oxygen Ionization and Hydrogen Overvoltage of Metals in the Solution 0.5 N NaCl + 0.01 N $Na_2CO_3$ + 0.01 N $NaHCO_3$ (pH = 9.2) in Oxygen Atmosphere With Mixing (Tomashov)**

| Metal | Electrode Potential, V | Overvoltage of Oxygen Ionization | | Hydrogen Overvoltage V at Current Density |
|---|---|---|---|---|
| | | 0.5 ma/cm² | 1 ma/cm² | 3 ma/cm² |
| Pt | +0.41 | 0.65 | 0.705 | 0.23 |
| Au | +0.325 | 0.775 | 0.85 | 0.565 |
| Hg | +0.29 | 0.80 | 1.62 | 1.255 |
| C (graphite) | +0.17 | 0.835 | 1.175 | 0.84 |
| Ag | +0.145 | 0.875 | 0.97 | 0.755 |
| Ni | +0.105 | 1.04 | 1.09 | 0.62 |
| Cu | +0.075 | 0.99 | 1.05 | 0.67 |
| Magnetite | +0.075 | 1.115 | 1.265 | 0.425 |
| Steel 18–8 | +0.055 | 1.12 | 1.185 | 0.58 |
| Ta | —0.05 | 1.38 | 1.50 | 0.925 |
| Fe (Cement) | —0.09 | 0.995 | 1.07 | 0.44 |
| Fe (oxyd.) | —0.115 | 1.105 | 1.18 | ..... |
| Fe | —0.135 | 1.00 | 1.075 | 0.485 |
| Sn | —0.16 | 1.175 | 1.215 | 1.09 |
| Co | —0.205 | 1.15 | 1.25 | 0.425 |
| Cr | —0.215 | 1.155 | 1.205 | 0.75 |
| Pb | —0.315 | 1.39 | 1.445 | 0.88 |
| Pig Iron | —0.325 | 1.055 | 1.09 | 0.455 |
| Cd | —0.48 | 1.38 | ..... | 1.16 |
| Zn | —0.73 | 1.675 | 1.75 | 1.02 |
| Al | —0.83 | ..... | ..... | 0.865 |
| Mg (oxyd.) | —1.42 | 2.84 | 2.945 | 1.845 |
| Mg | —1.775 | 2.51 | 2.55 | ..... |

The values in the last three columns are negative.

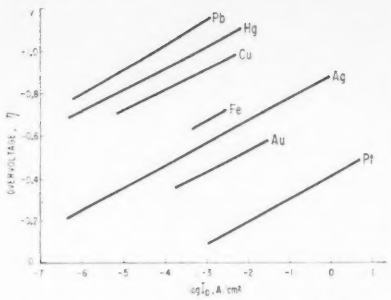


**Figure 110—Relation between the hydrogen overvoltage for different metals, and the current density (Dole).**

that is, an overvoltage) facilitates discharge of hydrogen ions and retards the inverse reaction of hydrogen ions transferring into the solution.

The first term in the parenthesis of (54) represents the rate of discharge of hydrogen ions, the second term represents the inverse reaction. For large overvoltages $\left( |\eta| \geqslant \frac{RT}{F} \right)$, the second term is negligible, and

$$I_D = FK_1 \cdot \exp\left(\frac{\alpha\eta F}{RT}\right) \qquad (55)$$

or

$$\log_{10} I_D = -\alpha \frac{\eta}{2.3\, RT/_F} + \log_{10}(K_2F) \qquad (56)$$

Since for $T = 25$ C, $\frac{RT}{F} = 0.025$ V, and since $\alpha = \frac{1}{2}$, the expression in (56) shows, that when the current is increased 10 times, the overvoltage is $-2\left(2.3\frac{RT}{F}\right) = -0.116$ V. The polarization curve shall be thought of in this case as caused by retardation of discharge of ions and will be called, for brevity, the curve of discharge polarization. Correspondingly, the overvoltage may be called the discharge overvoltage.

There are cases, however, when the rate of the whole process is determined not by one partial reaction, but by several. The relation between the rate of the process (or the current density) and the overvoltage is then much more complicated.

Figure 108 illustrates the curve for a process which is determined by both the ion discharge and diffusion. At low current densities, diffusion plays only a small part, and the rate of the process depends essentialy upon the rate of discharge of the ions (section "a" of the curve). At high current densities the consumption of ions is high, and their supply resulting from diffusion determines the rate of the whole process (section "c" of the curve). Between these two extremes is an intermediate part (section "b" of the curve) where both partial reactions jointly control the process.

Now consider separately the hydrogen overvoltage, which is connected with the cathodic reduction of hydrogen ions to the hydrogen molecule, and the overvoltage of oxygen reduction, that is, of cathodic reduction of oxygen to the hydroxyl ion.

It already is known that the potential of the cathode at which hydrogen is discharged in the absence of oxidizers (regardless of whether the cathode is polarized by an outside source of current, or by dissolution of the anode in a corrosion cell) is not equal to the potential of a reversible hydrogen electrode under these conditions. The difference between the cathodic potential and that of a reversible hydrogen electrode in the given conditions is called hydrogen overvoltage $\eta_H$.

Denoting the cathode potential by $E_K$ and that of a reversible hydrogen electrode by $E_H$

$$\eta_H = E_H - E_K \qquad (57)$$

The overvoltage makes the cathode more negative. When it is said that the overvoltage is increasing, it is meant that the potential of the cathode is decreasing.

The following basic regularities govern the hydrogen overvoltage: (1) The hydrogen overvoltage depends upon the cathode material. (2) It increases with increase in the density of the polarizing current. With very weak polarizing currents, in the range of about $10^{-5} - 10^{-4}$ ma per cm², the overvoltage increases linearly with the current density.

$$\eta_H = K_1 I_D \qquad (58)$$

(where $I_D$ is the density of the polarizing current, and $K_1$ is a factor of proportionality) until it reaches a value of approximately 50 mv.

For higher density of the polarizing current and for values of $\eta > 50$ mv the overvoltage increases logarithmically with the current density according to the Tafel equation

$$\eta_H = a + C \log_{10} I_D \qquad (59)$$

where "a" and "C" are constants.

The constant "a" is simply the overvoltage for a selected standard current density such as 1 ma per cm². When the current density is smaller than the selected value of "a," the numerical value of the second term of Tafel's equation will be negative.

The constant "C" does not depend on the nature of the metal and is about the same (0.10 to 0.12) for all metals. It is evident that the empirically obtained Tafel's equation is identical with Equation (56). The relation between $\eta_H$ and the current density is given schematically in Figure 109. If the initial potential of the cathode in the absence of current, $E_K^\circ$ is more positive than the potential of the hydrogen electrode under the same conditions ($E_K^\circ > E_H^\circ$), then with a decreasing current density the curve, instead of being logarithmic, will become a straight line and will approach the value of the hydrogen electrode under the same conditions. An example of this kind of a curve for Pt in 0.5 N $H_2SO_4$ is given in Figure 109. When the initial potential of the cathode $E_K^\circ$ is more negative than that of the hydrogen electrode: $E_K^\circ < E_H^\circ$, the curve approaches the original cathode potential, for decreasing current densities, as shown in Figure 109 on curves for Pb in 0.5 N $H_2SO_4$, Zn in 1N NaCl, and Ni in 0.15 N HCl.

The values of hydrogen overvoltage for different metals at various current densities are given in Table 6. Figure 110 represents the relation between the hydrogen overvoltage for some metals, and the logarithm of the current density ($\log I_D$).

The equal slope of the straight lines in this diagram proves that the factor "c" is actually a constant for most of the metals. As mentioned before, the value of "c" is in good agreement with the theoretical value $\left(2 \times 2.3\frac{RT}{F} = 0.116\right)$, ranging between 0.10 and 0.12. The very low values of hydrogen overvoltage for platinized platinum are caused by the fact that the true surface of such an electrode is hundreds or thousands of times larger than the surface of a smooth electrode. The true current density is correspondingly smaller.

The observed value of "c" and its constancy show that the hydrogen overvoltage is actually determined by the retarded discharge of hydrogen ions. The value of "c" would be different, if the overvoltage were caused by another link of the reaction chain.

It should be mentioned that accurate measurements of hydrogen overvoltage are quite difficult. They depend considerably on the purity of the metals.

3. Experimental data show that hydrogen overvoltage depends only slightly on the concentration of hydrogen ions in the solution. A. N. Frumkin developed the theory of this phenomenon. The overvoltage does depend on: the nature of the solvent, substances in the solution acting on the surface, and the presence of some polyvalent ions and of cations that can be discharged at the cathode. The presence in the solution of oxidizers, particularly of oxygen, may also greatly influence the results.

4. A temperature increase of 1 degree C lowers the overvoltage approximately 2 mv.

5. Pressure apparently does not influence the overvoltage.

6. The overvoltage of alloys has not yet been studied thoroughly. It changes continuously (with the composition) in some solid solutions; in others it changes in sudden steps. The overvoltage of a eutectic system apparently depends not only on the component with the lower overvoltage, but also on the second component.

At very low current densities, the small amount of hydrogen which is evolved at the cathode, adheres to the surface of the cathode because of the adsorption forces. After gradual accumulation, hydrogen might slowly be removed, by diffusion, from the cathode into the metal and into the solution, and might in the latter case escape through the bulk of solution into the gas phase.

At higher current densities, hydrogen may be evolved at the cathode in considerable quantities. Saturation might take place while the speed of diffusion is not balanced by hydrogen evolution at the cathode by discharge of hydrogen ions. Then the removal of hydrogen from the cathode takes place by formation of hydrogen bubbles. The latter, after reaching a certain size, may overcome the surface forces by means of the hydrostatic force, and separate from the cathode surface. The size of the bubbles apparently depends on many factors: the nature of the metal, surface condition, electrode potential, composition of the electrolyte, presence of substances active at the surface, etc. The time of bubble formation depends not only on the material of the electrode and on the current density, but on a number of other conditions.

Thus, the removal of hydrogen from the cathode (i.e., hydrogen depolarization), might proceed in two ways: at very low current densities, by hydrogen diffusion, and at higher current densities, by formation of hydrogen bubbles and their removal from the surface.

It must be pointed out that the points on the cathode where hydrogen ions are discharged, by no means coincide with those where the hydrogen bubbles are formed.

From the practical standpoint, interest is centered on corrosion proceeding with a noticeable rate. The possibilities of hydrogen removal by diffusion at a low rate of hydrogen formation at the cathode should not be forgotten. In the main, though, interest will be centered on hydrogen depolarization by removal of hydrogen from the cathode surface as gas bubbles.

It was thought formerly that the value of hydrogen overvoltage is connected with the formation of the first bubbles of hydrogen at the cathode, rather than with a definite current density, and that the formation of bubbles corresponds to the "free current passage through the solution." It was believed that on the potential-current density curve this point was marked by a sudden change of direction. However, recent, more accurate investigations have shown that the relation between the potential and the current density is logarithmic, the change of direction depends on the chosen scale, and has no physical meaning. The overvoltage corresponding to the beginning of hydrogen bubble formation, is called "the minimum overvoltage." Although this conception is somewhat obsolete and to some extent has no definite meaning, it will be used because the great majority of measurements have dealt with this "minimum overvoltage." Besides, this quantity is sometimes useful when dealing with corrosion, despite the lack of precision connected with it. In the tabulation (see Table 7) the values of the minimum overvoltage are given as measured by several investigators.

The actual values of hydrogen overvoltage which have to be used in corrosion problems, often disagree with the tabulated values. The latter are obtained under more definite experimental conditions (i.e., for very pure metals and solutions, with definite surface conditions, etc.), whereas in corrosion, besides $H^+$, there are always extraneous ions, impurities in commercially available alloys, possibly films covering parts of the cathode, and some other factors, which distort the value of overvoltage as obtained under "clean conditions." The overvoltage that must be used can be expressed by

$$\eta_H' = \eta_H + \Delta\eta_H,$$

where $\eta_H'$ is the actual overvoltage, $\eta_H$

## TABLE 7—Hydrogen Overvoltage in Metals

| Metal | MINIMUM OVERVOLTAGE (First Appearance of Hydrogen Bubbles) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Caspari 1899 | Mueller 1900 | Cohen and Daneberg, 1901 | Harkins 1910 | Newberry (commut. method) 1914–1916 | Foerster 1922 | Til & Hammer-smith 1923 | Evans (Summary) 1926 | Centner-swer & Straumanis 1925 |
| Al | .... | .... | 0.27 | .... | 0.18 | .... | .... | .... | .... |
| Ta | .... | .... | .... | .... | 0.39 | .... | .... | .... | .... |
| Cr | .... | .... | .... | .... | 0.41 | .... | .... | .... | 0.41 |
| Mo | .... | .... | .... | .... | 0.25 | .... | .... | .... | .... |
| W | .... | .... | .... | .... | 0.28 | .... | .... | .... | .... |
| Fe | .... | .... | 0.03 | .... | 0.24 | .... | 0.175 | 0.05 | 0.28 |
| Co | .... | .... | .... | .... | 0.23 | .... | .... | .... | 0.29 |
| Ni | 0.21 | 0.03 | 0.14 | 0.15 | 0.70 | 0.29 | 0.137 | 0.15 | 0.32 |
| Pd | 0.46 | 0.24 | .... | 0.02 | 0.00 | 0.000 | 0.0000 | .... | .... |
| Pt (platinized) | 0.005 | 0.01 | 0.0 | 0.002 | .... | 0.000 | $0.0000_2$ | very low | .... |
| Pt (smooth) | 0.09 | 0.07 | .... | 0.07 | 0.20 | 0.08 | 0.080 | 0.1 | 0.02 |
| Cu | 0.23 | 0.03 | 0.19 | 0.25 | 0.34 | 0.415 | 0.19 | 0.25 | 0.40 |
| Ag | 0.15 | 0.05 | 0.07 | 0.13 | 0.33 | 0.495 | 0.097 | 0.1 | 0.30 |
| Au | 0.02 | 0.06 | 0.05 | .... | 0.38 | 0.050 | 0.0165 | 0.02 | .... |
| Zn | 0.70 | .... | .... | .... | 0.70 | 0.70 | .... | 0.7 | 0.78 |
| Cd | 0.48 | .... | .... | .... | 0.50 | 0.48 | .... | 0.5 | >0.66 |
| Hg | 0.78 | 0.42 | 0.44 | 0.74 | 0.61 | 0.80 | 0.570 | 0.8 | 0.8 |
| Tl | .... | .... | .... | .... | 0.55 | .... | .... | .... | 0.78 |
| C (graphite) | .... | .... | .... | .... | 0.33 | 0.335 | 0.335 | .... | .... |
| Sn | 0.53 | 0.43 | .... | .... | 0.44 | .... | .... | 0.5 | 0.73 |
| Pb | 0.64 | 0.35 | 0.36 | 0.62 | 0.45 | 0.78 | 0.402 | 0.6 | 0.70 |
| As | .... | .... | .... | .... | 0.41 | .... | .... | .... | 0.54 |
| Sb | .... | .... | .... | .... | .... | .... | .... | .... | 0.35 |
| Bi | .... | .... | .... | .... | 0.38 | .... | .... | .... | 0.67 |

## Hydrogen Overvoltage at Different Current Densites ma/cm²

| Metal | Knobel, Kaplan' Eisenmann, 1923 | | | | Dole (Summary) 1935 | | Hicling & Salt 1941 | | | | Frumkin and His School 1936–1941 | Tomashov 1943 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1000 | | | | | | | |
| | 0.1 | 1 | 10 | 100 | Const. a | Const. b | 1 | 10 | 100 | 1000 | 1 | 3 |
| Mg (oxidized) | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | ..... | 1.845 |
| Al | 0.50 | 0.57 | 0.83 | 0.97 | .... | .... | .... | .... | .... | .... | ..... | 0.865 |
| Ta | .... | .... | .... | .... | (1.7) | (0.21) | .... | .... | .... | .... | ..... | 0.925 |
| Cr | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | ..... | 0.75 |
| W | .... | .... | .... | .... | .... | .... | 0.22 | 0.30 | 0.42 | 0.50 | ..... | .... |
| Fe | 0.32 | 0.66 | 0.83 | 0.97 | 1.02 | .... | .... | .... | .... | .... | 0.35 | 0.485 |
| Co | 0.22 | 0.40 | 0.56 | 0.82 | .... | .... | .... | .... | .... | .... | ..... | 0.425 |
| Ni | .... | 0.63 | 0.75 | 1.05 | .... | 0.113 | .... | .... | .... | .... | 0.25 (0.37) | 0.62 |
| Pd | .... | 0.14 | 0.32 | 0.72 | .... | .... | .... | .... | .... | .... | ..... | .... |
| Pt (platinized) | .... | .... | .... | .... | .... | .... | 0.02 | 0.04 | 0.06 | 0.07 | ..... | .... |
| Pt (smooth) | .... | 0.024 | 0.068 | 0.290 | 0.48 | 0.12 | .... | .... | .... | .... | ..... | 0.23 |
| Cu | 0.35 | 0.48 | 0.58 | 0.80 | 1.25 | 0.103 | .... | .... | .... | .... | ..... | 0.67 |
| Ag | 0.30 | 0.47 | 0.76 | 0.87 | 0.95 | 0.118 | .... | .... | .... | .... | 0.57 | 0.755 |
| Au | 0.12 | 0.24 | 0.39 | 0.59 | 0.80 | 0.123 | 0.18 | 0.26 | 0.40 | 0.45 | ..... | 0.565 |
| Zn | .... | 0.72 | 0.75 | 1.06 | .... | .... | .... | .... | .... | .... | ..... | 1.02 |
| Cd | 0.65 | 0.98 | 1.13 | 1.22 | 1.25 | .... | .... | .... | .... | .... | ..... | 1.16 |
| Hg | 0.55 | 0.93 | 1.04 | 1.07 | 1.4 | 0.117 | 1.0 | 1.15 | 1.25 | 1.25 | 0.75 (1.08) | 1.255 |
| C (graphite) | 0.32 | 0.60 | 0.78 | 0.98 | 1.1–1.34 | 0.115 | .... | .... | .... | .... | ..... | 0.84 |
| Sn | 0.40 | 0.86 | 1.08 | 1.22 | 1.24 | .... | 0.7 | 0.9 | 1.0 | 1.0 | ..... | 1.09 |
| Pb | .... | 0.52 | 1.09 | 1.18 | (1.45) | (0.20) | 0.57 | 1.2 | 1.25 | 1.25 | 1.16 | 0.88 |
| Bi | .... | 0.78 | 1.05 | 1.14 | .... | .... | 0.75 | 0.9 | 1.04 | 1.13 | ..... | .... |

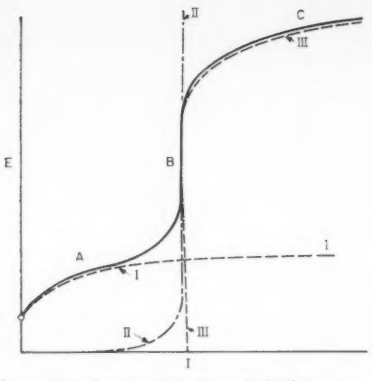


Figure 111—Complex cathodic polarization curve. Elemental curves (Tomashov): I—Overvoltage of oxygen reduction, II—Concentration polarization (oxygen diffusion), III—Hydrogen overvoltage.

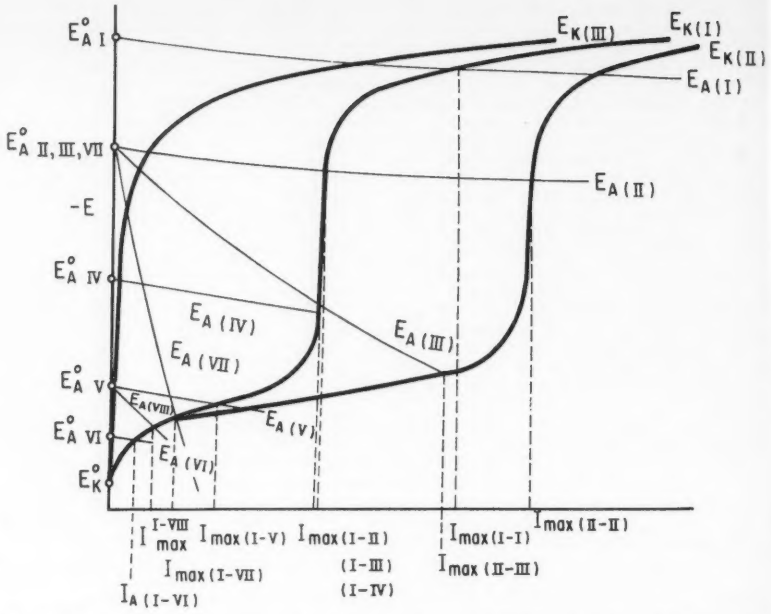


Figure 112—Evans' diagram for several typical relations between cathodic and anodic polarization curves (Akimov).

the tabulated overvoltage, $\Delta\eta_H$ is a correction accounting for actual conditions.

Consider now the oxygen overvoltage at the cathode. The process

$$O_2 + 4e + 2H_2O + 4m\ H_2O \rightleftarrows 4\,OH^- m H_2O,$$

probably, consists of at least the following interconnected reactions:

(1) For the cathode polarization—diffusion of oxygen from the solution toward the cathode:

$$O_2 \rightleftarrows O_2;$$

Solution — Boundary liquid/cathode

(2) Adsorption of oxygen and dissociation of molecules (into atoms):

$$O_2 \rightleftarrows 2\,O;$$

(3) Ionization:

$$O + 2e \rightleftarrows O^{--};$$

(4) Formation of the hydroxyl ion:

$$O^{--} + H_2O + 2m\ H_2O \rightleftarrows 2OH^- \cdot m\ H_2O;$$

(5) Transfer of the hydroxyl ions from the cathode into the bulk of solution:

$$OH^- \rightleftarrows OH^-$$

Solution-cathode interface — Bulk of solution

In addition, possibly, some secondary reactions may occur, such as hydrogen peroxide formation

$$O_2 + 2HOH + 2e \rightleftarrows H_2O_2 + 2OH^-.$$

The process of cathodic reduction of oxygen has not been studied as intensively as the reduction of hydrogen, and is therefore less understood.

According to the above definition, the oxygen reduction overvoltage (or the overvoltage of oxygen ionization) $\eta_{O_2}$ is equal to

$$\eta_{O_2} = E_K - E^{\circ}_{O_2},$$

where $E_K$ is the cathode potential, and $E^{\circ}_{O_2}$ is the potential of a reversible hydrogen electrode for given conditions (see Clark's diagram, Figure 105 in the first section of the present chapter).

According to recent results,[11] the overvoltage as a function of current density for the reaction of oxygen reduction, can be expressed by the Tafel equation (59), with the value of about 0.116 for the constant "c." The values of overvoltage for the reaction of cathodic oxygen overvoltage are given in Table 7. With decreasing current density, the overvoltage curve approaches the value of the cathodic potential of the electrode in the absence of current, as it is the case for hydrogen overvoltage.

The solubility of oxygen in the electrolytes is low. When the air under atmospheric pressure is in contact with water, one obtains approximately 0.0001 N hydrogen in solution. Therefore, the overvoltage curve, which is determined by the discharge of $O + 2e \rightleftarrows O^{--}$ (reaction 3), changes into a concentration polarization curve, even for relatively low current densities, because of the lack of oxygen in the solution. Thus the cathodic polarization curve, or the overvoltage curve, is obtained, similar to the one represented in Figure 108.

One obtains a similar relationship if there is some oxidizer other than oxygen in the solution, such as I in a solution of KI. Here iodine is reduced to iodine-ion according to

$$I_2 + 2e \rightarrow 2I^-.$$

This reaction also produces a certain value of overvoltage, depending on the conditions. At higher current densities, when there is not enough iodine in the solution in the vicinity of the electrode to conduct the reduction with a corresponding speed, the discharge polarization curve changes into a concentration polarization curve.

### 3. Evans' Diagram for Real Processes

The cathodic polarization curve for moderately strong acids in the presence of atmospheric oxygen usually has a complex shape, illustrated in Figure 111. The lower part of curve A is controlled mainly by the oxygen reduction at the cathode; the middle part B is connected with retardation of oxygen diffusion toward the cathode, and the upper part of the curve C corresponds to the evolution of hydrogen at the cathode. The complete curve is actually a resultant from the superposition of elemental polarization curves I, II and III, corresponding to the above discussed processes. When the concentration of oxygen in the solution is high, diffusion does not play an important part, and the total polarization curve has the shape of curve I. If the hydrogen ion concentration in the solution is sufficiently higher, the polarization curve corresponds from the very start to the curve of hydrogen overvoltage, that is to curve III, shifted to the origin of the coordinate system.

A number of very important regularities in corrosion processes are connected with this complex cathode polarization curve. In the overwhelming number of cases the curve of anodic polarization is only slightly bent or is a straight line. The Evans diagram for actual processes is then represented by the intersection of the complex cathodic and the simple anodic curves.

Consider cases depicted in Figure 112. Here one finds three curves $E_K$ (I), $E_K$ (II) and $E_K$ (III), starting from the same initial cathode potential $E^{\circ}_K$. The curve $E_K$ (I) is the complex cathode curve for a solution with pH between 5 to 9, in the presence of atmospheric oxygen under moderate mixing. The curve $E_K$ (II) corresponds to a richer supply of oxygen at the cathode surface; this can be achieved, for instance, by more vigorous stirring. The curve $E_K$ (III) is associated with an almost complete absence of oxygen in solution. The curve rises steeply from the value $E_K$, and the part A is practically nonexistent. The anodic curves are given in Figure 112 ($E_A$ (I), $E_A$ (II), $E_A$ (III), etc.) as slightly bent lines (almost straight).

Part of the cathodic curve intersecting the anodic curve corresponds to the type of cathodic process. Thus, if the

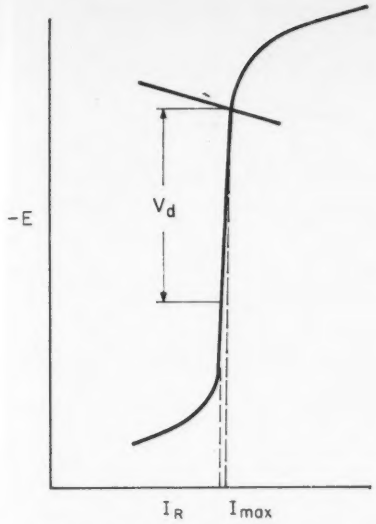


Figure 113—Diagram illustrating independence of corrosion current from the electrical resistance of a corrosion cell for processes with oxygen depolarization (Akimov).

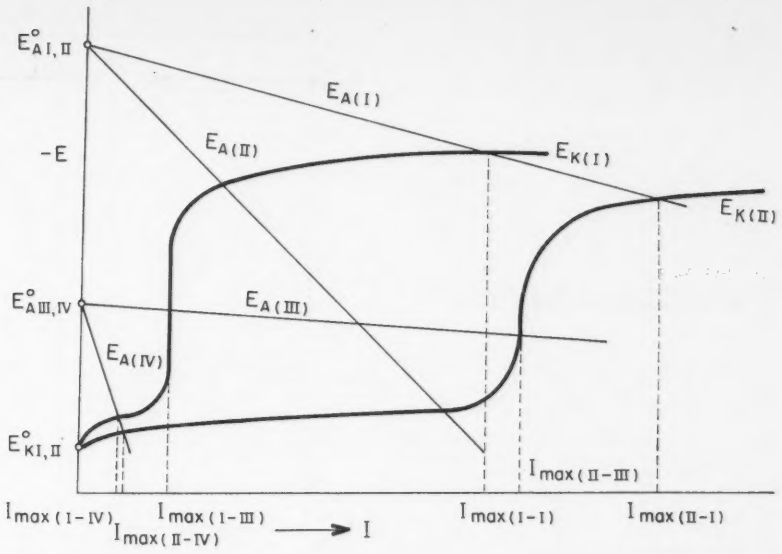


Figure 114—Evans' diagram for a case when the cathode area II is five times greater than that of cathode I (Akimov).

intersection is in part A (Figure III), the result is a corrosion process with oxygen depolarization, whereas if it is in the part C, corrosion with hydrogen depolarization is predominating. If the intersection of cathodic and anodic curves is in the beginning of the part C, the hydrogen and oxygen depolarizations are comparable in their importance.

It follows that from Figure 112, when the initial anodic potential is nearly equal to the initial cathodic potential, the corrosion process of a complex cathodic curve corresponds to the process with oxygen depolarization. Its rate is given by neutralization at the cathode (diagram $E_K$ (I) and $E_A$ (VI)). With a more negative anode, the process is governed by oxygen depolarization, the rate of which depends on diffusion of oxygen to the cathode (diagram $E_K$ (I) and $E_A$ (IV). Finally, with a sufficiently negative anode, the corrosion proceeds with hydrogen depolarization (diagram $E_K$ (I) and $E_A$ (I)). It follows also from the diagram that the more the anode is polarized, the more likely will the corrosion process, other conditions being equal, correspond to the part A, the oxygen depolarization, with a rate given by the rate of discharge at the cathode. In this connection note diagrams $E_K$ (I) and $E_A$ (VII), $E_K$ (I) and $E_A$ (III) and $E_K$ (I) and $E_A$ (II).

It is important to note that the maximum current depends both on the initial anodic potential, for the same slopes of anodic curves, and on the slopes of anodic curves for the same $E^{\circ}_A$, when the intersection of the anodic and cathodic curves takes place in parts A and C of the complex cathodic curve. In this connection note diagrams $E_K$ (I) and $E_A$ (VI), $E_K$ (I) and $E_A$ (V), and $E_K$ (I) and $E_A$ (V), $E_K$ (I) and $E_A$ (VIII). When, however, the process is controlled by the rate of oxygen diffusion at the cathode (part B of the complex cathodic curve), then, within certain limits, the maximum corrosion current is influenced neither by the initial anode potential, nor by the anode polarization. This can be seen in diagrams $E_K$ (I) and $E_A$ (II) and $E_K$ (I) and $E_A$ (IV); $E_K$ (I) and $E_A$ (II) and $E_K$ (I) and $E_A$ (III). Furthermore, under these conditions, the corrosion current should not be affected by wide variations of the electrical resistance. This follows from the structure of the Figure 113. The value of the maximum corrosion current I max (resistance very small), and that of current $I_R$ corresponding to high electric resistance (large potential difference $V_{(d)}$) are nearly the same, because of the steep slope of the part B of the cathodic curve.

It follows from Figure 112 that the shape of the cathodic curve strongly influences the value of I max. The richer the supply of oxygen is at the cathode, the higher the corrosion current (see, for instance, I max for the diagram $E_K$ (I) and $E_A$ (III) and $E_K$ (II) and $E_A$ (III), as well as $E_K$ (I) and $E_A$ (II) and $E_K$ (II) and $E_A$ (II)).

In Figure 114 two cathodic curves are given, $E_K$ (I) and $E_K$ (II); the first curve has a polarization approximately five times larger than the second, which might be caused, for instance, by a difference of the cathodic areas. It follows from the diagram that there should be no direct proportionality between the area and the magnitude of the corrosion current, when the corrosion process corresponds to the part A of the cathodic curve (see $I_{max}$ (I - IV) and $I_{max}$ (II - IV)). The same is true with respect to processes of the part C of the cathodic curve, that is, hydrogen evolution (see, for instance $I_{max}$ (I - II) and $I_{max}$ (II - I). The current is proportional to the cathode area (see $I_{max}$ (I - III) and $I_{max}$ (II - I) only when the corrosion process is controlled by the rate of diffusion of oxygen to the cathode (i.e., when it belongs to the part B of the cathode curve).

It follows from Figure 114 also that the greater the polarization, and therefore the steeper the cathodic curve, the more likely it is, other conditions being equal, to arrive in the range of hydrogen depolarization processes.

Thus, it is seen that a number of important regularities are connected with the shape of the complex cathodic curve. It will be shown later that conclusions based on Evans' diagrams for real processes are confirmed by the experimental data. It should be noted that usually when the corrosion process in naturally occurring conditions is connected with oxygen depolarization, it is controlled by the rate of diffusion, which corresponds to part B; when the process is connected with hydrogen evolution, it is controlled by the rate of the discharge; this corresponds to part C. The cases when the rate of discharge with the oxygen depolarization, or the rate of diffusion, with hydrogen depolarization, control the process, are quite rare in practice.

### 4. Electrochemical Cell with Hydrogen Depolarization[6, 7, 8, 10, 12, 13]

It is convenient to conduct the study of processes with hydrogen depolarization, as well as of other phenomena in the realm of corrosion, by using first a model of a microelement (i.e., a standard galvanic cell with an electrode area sufficient for making all electrochemical measurements).

This method considerably facilitates the investigation because many quantities can be determined experimentally, whereas in exploring the working of a microcell one can deduce the processes only on the basis of some indirect data. It is extremely difficult to measure directly the anodic and cathodic potentials, and the internal and external resistances of a microcell.

The model method has proven valuable in corrosion problems. It should be kept in mind, however, that an uncritical attitude toward the results obtained with the model might lead to gross errors.

The functioning of a microcell is, of course, more complex than the working of a particular model of a galvanic cell—one cannot necessarily draw conclusions about the microcell from the results with the model. All pecularities of the working of the mircocell must be considered with respect to a number of factors. Some of these are: (1) the electrodes are of microdimensions, (2) it is a multielectrode system, (3) the electrodes are short-circuited with each other.

First it is necessary to find the con-

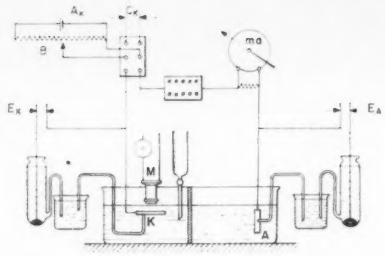


Figure 115—Apparatus for study of corrosion processes with cathodic polarization (Akimov).

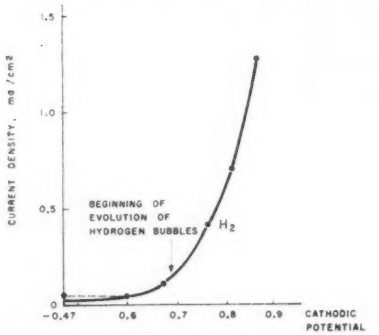


Figure 116—Current in the platinum-cadmium cell as a function of platinum potential. An external source of current is used for polarization.

ditions for the working of an electrochemical cell with evolution of hydrogen at the cathode.

It is known that for very low current densities the hydrogen overvoltage is very small. Under these conditions, when there is some electrochemical heterogeneity, the electrochemical cell will work with hydrogen depolarization, if the anodic potential $E_A$ is more negative than the hydrogen electrode potential $E_H$ in given conditions, that is, for a given hydrogen ion concentration, hydrogen pressure, temperature, etc. Thus, in considering the possibility of hydrogen evolution at the cathode, even at a low rate (very low current densities), one may neglect the hydrogen overvoltage at the cathode.

However, this condition does not determine the rate of the process. And yet, in corrosion, interest is centered not in the theoretical possibility of a process, but primarily in its actual rate. If the corrosion process is possible, but actually has a very low rate, these corrosion losses in many cases can be neglected and the metal or the construction can be considered chemically stable. The problem then is to find the conditions for the corrosion process having a given minimum rate of practical importance.

It is first necessary to agree on the value of such a rate. In many cases one can assume on practical considerations, that destruction of metal with density 7 to 8, at the rate up to 0.1 g per 1 $m^2$ per hour corresponds to a very stable metal. With the rate increased 10 times (e.g., 1 g per 1 $m^2$ per hour), the metal is still quite stable; at higher rates, the metal will be considered of little stability. These values of the corrosion rate are, of course, strictly equivalent to the amount of hydrogen evolving at the cathode, and to the current density. The corrosion rate of 1 $g/m^2 \cdot h$ corresponds to hydrogen evolution of about 1 $cm^3$ $H_2$ per $cm^2$ per day, and to a current density of 0.1 $ma/cm^2$. The borderline between chemically stable and unstable conditions of metal corrosion corresponds to these values. The choice of this limit is, of course, arbitrary, and has a meaning only as an average value. This limit might be shifted one way or another, depending on material requirements in working conditions, nonuniformity of corrosion, and other factors. Undoubtedly, with the rate of corrosion of 1 $g/m^2 \cdot h$, or 0.1 $ma/cm^2$, a rate arbitrarily considered the borderline between chemical stability and instability, the hydrogen overvoltage must be considered. The condition for the process with a given rate is then:

$$E_A < E_H + \eta_{0.1} + \Delta\eta, \qquad (60)$$

where $\eta_{0.1}$ is the overvoltage at a cathodic current density of 0.1 $ma/cm^2$, and $\Delta\eta$ is the correction for actual conditions.

This condition can be written somewhat differently, substituting for $\eta_{0.1}$ its value from Tafel's equation (59):

$$E_A < E_H + (a + c \log I_D) + \Delta\eta,$$

with $I_D = 0.1$ $ma/cm^2$.

The appearance of hydrogen bubbles at the cathode in observable quantities often corresponds to a current density of 0.1 to 1 $ma/cm^2$.

Consider now the following example. A pair of platinum-cadmium (Pt - Cd) electrodes are selected which have approximately the same area. The pair is placed in a neutral solution of 3 percent NaCl (see Figure 115). By means of the battery $A_K$ and the potentiometer B, the cathode K can be polarized and, simultaneously, the current density in the cell and the anodic and cathodic potentials measured. The moment of appearance of evolution of hydrogen bubbles at the cathode can be exactly determined with a microscope M.

When oxygen is absent from the solution, hydrogen evolution will proceed even without polarization of the cathode, because the condition $E_A < E_H$ is fulfilled. However, the rate of corrosion (and the hydrogen evolution) will be very low, corresponding to a very weak current ($< 0.1$ $ma/cm^2$); there will be no hydrogen bubbles at the cathode, not even of microscopic dimensions. By means of cathodic polarization of the platinum electrode, its potential is shifted toward negative values; at the same time, the current in the cell will increase gradually. Figure 116 shows the results of this experiment. It follows from the diagram, that the current density of 0.1 $ma/cm^2$, which by convention corresponds to dangerous cor-

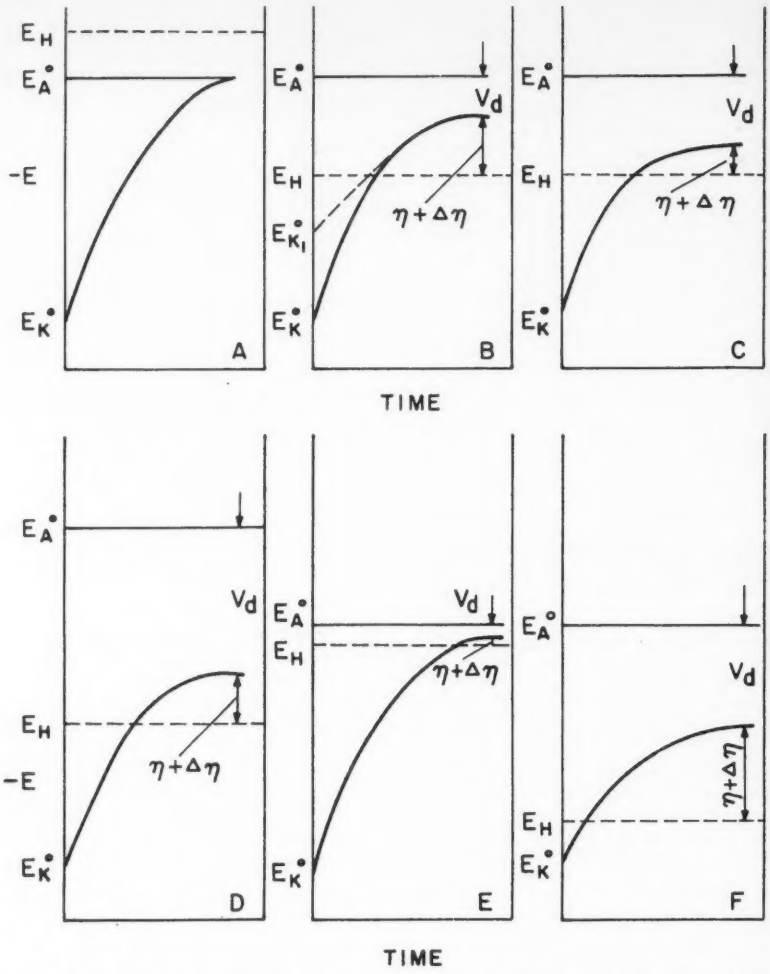


Figure 117—The changes of potentials of the cell after closing the circuit for different cases (Akimov).

**TABLE 13—Mg/M Cell in a 3 Percent NaCl Solution (Kronig and Kostylev)**

| Cathode M | Average Current in the Mg/M Cell, ma | Cathodic Overvoltage, —V | Electrode Potential $E_M$, V | Initial Potential Difference Mg/M Cell, V |
|---|---|---|---|---|
| Pt | 67 | 0.1 | +0.3 | 1.7 |
| Ni | 33 | 0.15—0.2 | —0.0 | 1.4 |
| Fe | 30 | 0.2 —0.3 | —0.5 | 0.9 |
| Al | 28 | 0.2 —0.3 | —0.6 | 0.8 |
| Cu | 20 | 0.2 —0.4 | +0.0 | 1.4 |
| Pb | 12 | 0.4 —0.7 | —0.26 | 1.14 |
| Zn | 4 | 0.7 | —0.83 | 0.57 |
| Hg | 0.1 | 0.78—0.8 | +0.25 | 1.65 |

**Note:** The electrode potential Mg in a 3% NaCl solution was —1.4V.

rosion (poor chemical stability), is obtained only after a considerable shift of the cathode potential (from —0.47 to approximately —0.67 v). Evolution of hydrogen bubbles at the cathode surface is observed about in the same range of current densities—approximately 0.1 ma/cm². Measurements show that the polarization changes the anode potential relatively little (only 20-30 mv).

An attempt will be made now to follow up the processes at the electrodes of the cell from the moment the circuit is closed until some stationary state is reached. The initial potentials of the anode and the cathode are denoted by $E°_A$ and $E°_K$, respectively. The rest of the symbols remain the same as above.

In Case A, the fundamental conditions (60) for the corrosion process having the given rate, $E_A < E_K$; $E_A \leqslant E_H$ are not fulfilled. In this case the cathodic potential will begin to change from the moment the circuit is closed, and will reach the potential of the anode: $E_A = E_K$. If the cell has some electrical resistance, however small, the current is zero. Since the potential difference is zero, this means that the rate of corrosion is zero, Figure 117A.

For all other cases (from B to F) considered below, the fundamental relation is fulfilled: $E_A < E_H$. It is assumed also, that in all cases the resistance of the cell is constant. Then the current, together with the corrosion rate, is proportional to the existing potential difference $V_d$.

The cases B and C differ one from another only in that the hydrogen overvoltage at the cathode is lower in case C than in case B. Figure 117B also shows that when the mutual positions of $E°_A$ and $E_H$ and the overvoltages do not change, then the changes of the initial potential of the cathode (for instance, from $E°_K$ to $E°_{K_1}$ do not affect the value of the existing potential difference $V_d$).

In case D, the initial anodic potential $E°_A$ is more negative than in case C. It follows from the diagram that $V_d$ is increasing, although $\eta + \Delta\eta$ is also increasing somewhat because of higher current density corresponding to higher value of $V_d$.

Cases E and F differ one from another by a different value of $E_H$. In case E, the hydrogen potential is much more negative than in case C. $V_d$ is lowered correspondingly. In case F, to the contrary, the value of $E_H$ is considerably more positive than in case C, and $V_d$ therefore is increasing, although the overvoltage is also increasing for reasons discussed in case D.

For the sake of simplicity changes of $E_A$ are not considered in the above cases when the circuit is closed. In processes with hydrogen depolarization, the anodic potential in a closed circuit often changes considerably less than does the cathodic potential.

According to Ohm's law, the expression for the current (or the rate of corrosion $\frac{dW}{dt}$)is:

$$\frac{dW}{dt} = k_1 I = k_2 I_D = \frac{V_d}{R_{total}} = \frac{E_K - E_A}{R_{total}}$$
$$= \frac{(E_H + a + C \log I_D + \Delta\eta)}{R_{total}} - E_A, \quad (61)$$

where $k_1$ and $k_2$ are constants, and $R_{total}$ is the total resistance of the cell. This equation cannot be solved algebraically, but it is possible to determine the value of $I_D$ or $I = I_D F_K$ graphically, if the rest of the quantities are known.

The expression (61) shows that the current and the corrosion rate at a given cell resistance are the higher, the more positive $E_H$ is. Also, the smaller the overvoltage (i.e., the value $\eta + \Delta\eta$), the more negative is the anodic potential. Considering also the changes of $E_A$, it is seen that the active potential difference, and the current are the greater, the less the anode is polarized (i.e., the less the anodic potential deviates from the initial potential $E°_A$ when the current is flowing).

As an example, consider another experiment again using a platinum-cadmium cell in a 3 percent solution of NaCl. This time an acid is being added gradually. No outside source of current is used here to produce polarization, Figure 118. The ordinates are the current densities in the cell, and the cathodic and anodic potentials; the values of pH are plotted against the abscissa. It is seen that the corrosion process is slow down to pH = 3, and the current density does not exceed the initial values for pH = 7 (i.e., it is less than 0.1 ma/cm².) Hydrogen evolution starts at approximately pH = 2; the gas bubbles can be clearly seen through the microscope. The experiment shows that the cathodic potential changes very little down to pH = 3. Below this value of pH, the cathodic potential changes increasingly faster toward positive values. The anodic potential also changes in the same direction, but much slower. $E_H$+ becomes more positive with the increase of hydrogen ion concentration, and the current is increasing accordingly. The values of pH between 3 and 2 mark the transition from the range that is chemically relatively stable to the range of chemical instability.

It might be well to consider one more example that shows the overvoltage at the cathode. A cell consisting of Mg plus an electrode of some other metal (M) was investigated in a 3 percent solution of NaCl. The electrode M, in contact with the magnesium electrode, was the cathode. Since magnesium has a very high electronegative potential (in a 3 percent solution of NaCl, $E_{Mg} = -1.4$ to $-1.7$V), the process was accompanied by hydrogen depolarization.

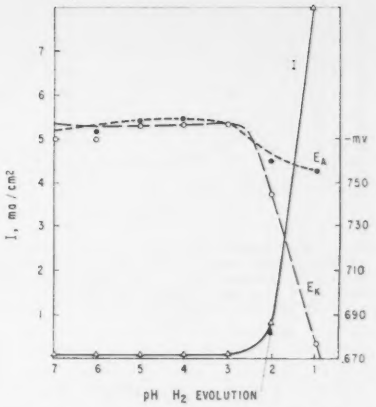


**Figure 118—Effect of the addition of acid in a platinum-cadmium cell. No outside source of current was used to produce polarization.**

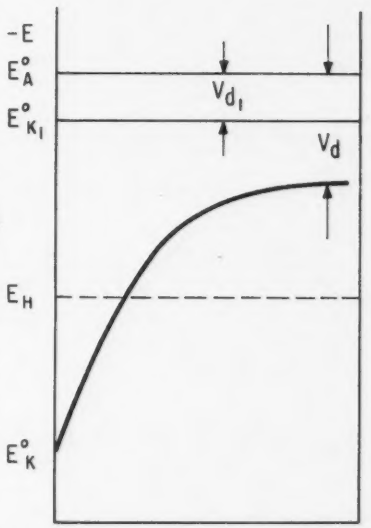


**Figure 119—Diagram explaining the limiting role of the cathodic potential ($E_K$) (Akimov).**

The results of this experiment are given in Table 13. It can be seen from these data that the current (and, consequently, the rate of anodic destruction of Mg) is related to the values of overvoltage: the higher the overvoltage, the weaker the current; the latter is independent of both the initial electrode potential of the cathode and of the initial potential difference. For instance, platinum and mercury in a cell with magnesium have almost identical potential difference, whereas the current in the cell Mg/Pt is almost 700 times higher than in the cell Mg/Hg. This is explained by a very low overvoltage at Pt and a very high one at Hg.

From the above data one might conclude that the value of the initial electrode

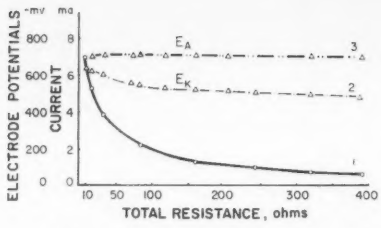


Figure 120—Changes of I, $E_K$ and $E_A$ by changing of the resistance from 11 to 391 Ohms Cu/Zn cell in a 0.1N HCl solution. Anodic and cathodic areas are each equal to 3 cm² (Akimov and Clark). 1—The measured current, 2—Cathodic potential, 3—Anodic potential.

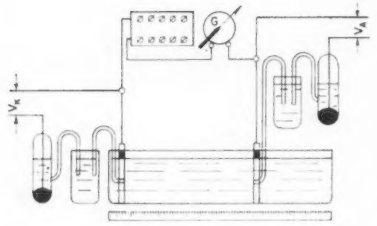


Figure 121—Apparatus for measuring I, $E_A$ and $E_K$ for changeable internal resistance of the system (Akimov and Clark).

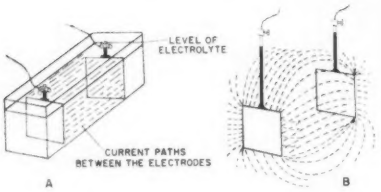


Figure 122—Current paths between the electrodes when (a) electrode area = cross-section of electrolyte, (b) electrode area << cross-section of electrolyte (Akimov).

potential of the cathode, $E°_K$, is of no importance in processes with hydrogen depolarization. However, this is by no means true. To begin with, the value of $E°_K$ determines which of the two electrodes in the cell is the anode and which the cathode. Even if the overvoltage at the electrode B is smaller than at the electrode A (i.e., $\eta_B < \eta_A$, but $E°_B \leqslant E°_A$), the electrode B cannot be the cathode. Secondly, when the initial cathodic potential is near to that of the anode, it might limit $V_d$ to some extent, and also the current in the cell. Figure 119 illustrates this. When the initial cathodic potential is $E°_K$, the working potential difference is $V_d$; if the initial cathodic potential is shifted to the level $E°_{K_1}$, then the working potential difference cannot be larger than $V_{d_1}$. The higher the cell resistance is, the more important $E°_K$ might become in limiting the working potential difference.

In analyzing the behavior of a cell with hydrogen depolarization, it is necessary to consider changes in composition taking place in the solution at the electrodes during the process. The solution at the cathode becomes depleted of hydrogen ions, because of hydrogen evolution, thus turning more basic (pH is increased); the solution layer at the anode is enriched in its own metallic ions. This by itself makes the working of the cell somewhat unstable. Diffusion tends to counteract the

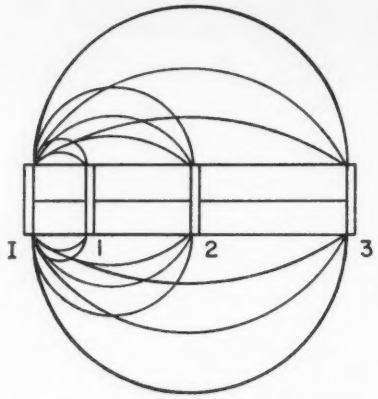


Figure 123—Possible paths for ion movement between working anode and cathode for identical electrode areas and varying electrode distances (Akimov).

concentration at the electrodes. The difference in composition of the solution at the electrodes and in the bulk will be still smaller when there is convection and mixing of the solution. In processes with hydrogen depolarization the evolution of gas bubbles provides some mixing of the immovable layer of liquid adjacent to the cathode.

Consider next the influence of changes in electrical resistance on the current and, therefore, on the rate of corrosion in a cell with hydrogen depolarization. If the anodic and cathodic potentials remained unchanged with the increase of the electrical resistance of the cell, the application of Ohm's law would show

$$I = \frac{E_K - E_A}{R}$$

an equilateral hyperbola. However, the decrease of current will lower the electrode polarization. Accordingly the cathodic potential will become more positive as the resistance increases and the anodic potential more negative.

Figure 120 shows the changes of I, $E_K$ and $E_A$ for the Cu/An cell in a 0.1N HCl solution, as functions of the cell resistance. The increase of the cell resistance has, of course, the same effect, whether it is the external or the internal resistance that is changing. There is, however, the following peculiarity: internal resistance can be changed, leaving all other factors unchanged, by spreading the electrodes (i.e., increasing the current path in the electrolyte, Figure 121.) When the areas of both electrodes are equal, and the cross-section of the electrolyte between them is the same everywhere and equal to the electrode areas, then the increase of electrode distance produces a proportional increase of resistance. In this case, all the current paths in the electrolyte are straight parallel lines, Figure 122a. When, however, the cross-section of the electrolyte is larger than the areas of the electrodes, the current paths are no longer straight lines. A considerable part of the current is carried by curvilinear paths (Figure 122b). A larger volume of the solution participates in the current passage; accordingly, the electrical resistance will be considerably lower for the same distance between the electrodes. The more the current paths are curved, the longer they are in comparison with the straight paths between the electrodes which are less effective. The curvilinear paths of

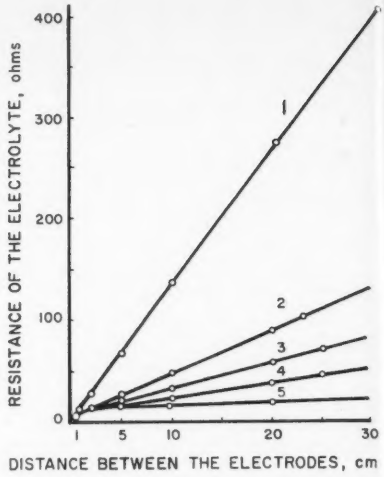


Figure 124—Resistance of an electrolyte (0.1N HCl) between two copper electrodes in containers of different cross-sections. Diameter of electrodes is 2.0 cm; diameter of containers is as follows: 1—2.0 cm; 2—3.6 cm; 3—4.5 cm; 4—6.0 cm; 5—30.0 cm.

the current are therefore of lesser importance, when the distance between the electrodes is small and the electrodes are large, than when the distances are large and the electrodes are small (Figure 123).

Figure 124 represents the results of resistance measurements in an electrolyte between electrodes of the same areas, but at different cross-sections of the electrolyte. They show that when the electrode area is equal to the cross-section of the electrolyte, the resistance increases linearly with the distance between the electrodes. But when the cross-section of the electrolyte is larger than the electrode area, the curves are not linear and are much flatter. When the cross-section of the electrolyte is 15 times larger than the electrode area (curve 5), increase of distance between the electrodes beyond 5 cm is not reflected in the increase of resistance.

In studying the influence of the anodic and cathodic areas on resistance changes, it should be kept in mind that changes of areas of any electrode always change the internal resistance. Figure 125 shows that by enlarging the area of one of the electrodes one can utilize a much larger volume of the electrolyte for the passage of current. However, further increases of the area of one of the electrodes do not effectively diminish the resistance, because the current paths become too long.

Figure 126 represents the change of internal resistance between two electrodes in a 0.1N NaCl solution; one of the electrodes had a constant area equal to 0.1 cm,² the area of the other electrode was varied. The results show that with the increase of the second electrode there is first a sharp drop of resistance, but with further increase of the area, the decrease of resistance becomes much slower.

Next consideration will be given to the influence of the anodic area on the current in a cell with hydrogen depolarization. Experiments show the relationship given in Figure 127. With the increase of anodic area, starting with very small values, there is a sharp increase of the current, and of the rate of cor-

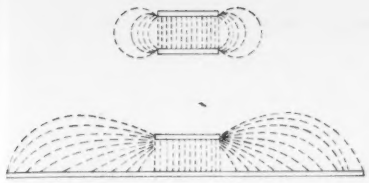

Figure 125—Possible paths for ion movement for equal and for different electrode areas (Akimov).

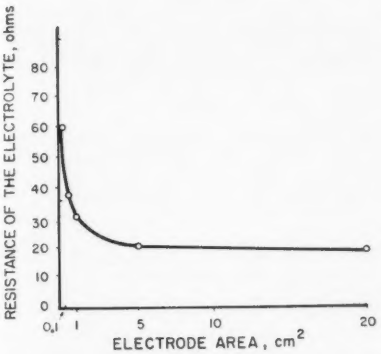


Figure 126—Internal resistance of a system, as a function of area of one of the electrodes in 0.1N HCl; area of the other electrode is 1 cm² (Akimov and Clark).

rosion; with further increase of the area the curve becomes parallel to the abscissa axis. There is no increase in current with increasing anodic area.

How can this shape of curve 1 in Figure 127 be explained? Studies have revealed that two factors are instrumental: change of the anodic potential and resistance drop following the increase of area. Figure 127 shows that the cathodic potential changes relatively little, whereas the anodic potential changes rapidly in the left part of the diagram, corresponding to the rapid increase of the current. Thus one may say that when the anodic area is very small, there is a very strong anodic polarization, leading to a decrease of the potential difference and of the current.

An increase of the anodic area until the latter becomes equal or even larger than the cathodic area, produces a sharp decrease of anodic polarization, and the anodic potential becomes constant regardless of the anodic area. It can be seen from the diagram that the resistance also increases considerably when the anodic areas are small; consequently, both the lowering of the anodic potential (making it more negative) and the decrease in electrical resistance with the increase of anodic area, work in the same direction: the current in the cell is increased when the anodic area is increasing from small values to areas comparable to those of the cathode.

Consider now the influence of the cathodic area on the current. The diagram in Figure 128 shows that the anodic potential changes little with the change of cathodic area. The cathodic potential changes considerably more, in the positive direction. Consequently, the larger the cathodic area, the smaller the polarization, and the larger the potential difference; correspondingly, the current and the rate of corrosion (destruction of the anodic area) are larger. The decrease of the internal resistance with

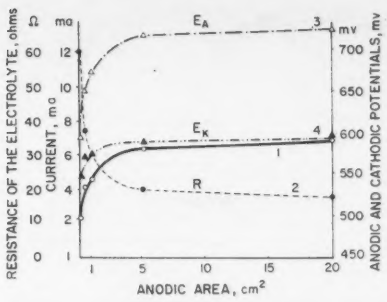


Figure 127—Changes of I, $E_A$, $E_K$ on $R_{internal}$ depending on changes of anodic area for Cu/Zn cell in 0.1N HCl (Akimov and Clark). Cathodic area 1 cm². 1—current (measured); 2—resistance of the electrolyte; 3—anodic potential; 4—cathodic potential.

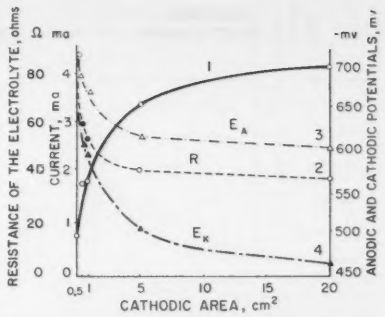


Figure 128—Changes of I, $E_A$, $E_K$, and $R_{internal}$ versus changes of cathodic area for Cu/Zn cell in 0.1N HCl (Akimov and Clark). The anodic area is 1 cm², I—current (measured), 2—resistance of electrolyte, 3—anodic potential, 4—cathodic potential.

the increase of cathodic area also produces an increase of the current.

It is suggested that the reader compare the experimental data obtained with models, with the deduction from the Evans' diagram in the previous section. He will convince himself that there is a complete agreement between the theory and experiment for processes with hydrogen depolarization.

### 5. Electrochemical Cell with Oxygen Depolarization[14, 15, 16, 17]

The rate of corrosion processes with oxygen depolarization is determined mostly by the rate of oxygen diffusion toward the metal surface. This kind of corrosion is extremely important, since it includes practically important processes such as corrosion of iron and steel in neutral salt solutions, corrosion of zinc in several neutral solutions, various cases of copper corrosion, etc. It should be recalled that in processes of this kind, the cathodic parts of a microelement should be considered as oxygen electrodes where oxygen reduction takes place (i.e., the interaction of oxygen atoms with electrons and water leading to the formation of hydroxyl ions). An overvoltage is connected with this process similar to the process of hydrogen discharge at the cathode. This quantity can be called the overvoltage of the reaction of oxygen reduction.* In the majority of practical cases, the concentration of oxygen in the solution corresponds to the oxygen solubility in a particular electrolyte. The presence and the constant replenishing of oxygen, which is the main substance necessary for the cathodic process, is of the greatest importance for processes with oxygen depolarization. Naturally, the oxygen electrode can exist only in the presence of oxygen, and only as long as oxygen, consumed in the process, is supplied to the electrode.

If the solution has a certain amount of oxygen, but the system is closed so that no additional oxygen can enter the system, then the corrosion process with oxygen depolarization can proceed only until the oxygen supply is exhausted.

When the metal is placed in an open container, oxygen can reach the cathodic sections by means of diffusion from the air through the solution, and the corrosion process might cause complete destruction of the metal.

If in the chain of interconnected processes, oxygen supply to the cathode is the slowest process, then the total rate of corrosion is determined essentially by this slowest link. Thus, the rate of oxygen supply to the cathode through the solution limits the total rate of corrosion. Factors facilitating oxygen supply to the metal increase the rate of corrosion and conversely, factors hampering this supply retard corrosion.**

Consider the factors affecting the rate of oxygen diffusion to the metal. The path of oxygen leading to the corroding metal is complex (see Figure 129).

The metal sample is placed horizontally, for the sake of simplicity. The molecules of oxygen (from the air) have to go through the following path: to cross the interface atmosphere-liquid (the so-called Laplace's layer), then to pass through the bulk of the solution to the metal surface. Finally, the oxygen molecules have to pass through the solution layer in the immediate vicinity of the sample (the so-called Prandtl's layer). This layer is relatively immovable being kept in place by adsorption forces. The thickness of the Prandtl's layer (also sometimes called the diffusion layer) is usually small; however, the layer is important because the passage of oxygen in it is particularly difficult. The oxygen can move in the solution not only because of diffusion, but also because of stirring, convection and thermal currents, etc.; oxygen can pass through the Prandtl's layer only by means of diffusion. Stirring decreases the thickness of Prandtl's layer; this thickness, for stirred solutions is considered to be between 0.02 and 0.1 mm. For unstirred solutions, the thickness is much greater and may reach 1 mm and even more. Stirring thus not only facilitates the passage of oxygen through the bulk of liquid, but also accelerates diffusion of oxygen through the Prandtl's layer by decreasing its thickness.

After the corrosion products begin to form on the metal surface, oxygen must, of course, also pass through the layer of the corrosion products. Thus, oxygen has to work its way through a fairly complex path, the greatest obstacle being the immovable liquid layer held at the metal surface by adsorption forces.

Diffusion is of importance mostly in the immovable liquid layer at the metal, especially when the passage of oxygen through the bulk of solution is facili-

* This is not to be confused with the overvoltage of oxygen evolution at the anode from the solution during electrolysis.

** When the metal is passivated by the large amount of oxygen (see Chapter VI).

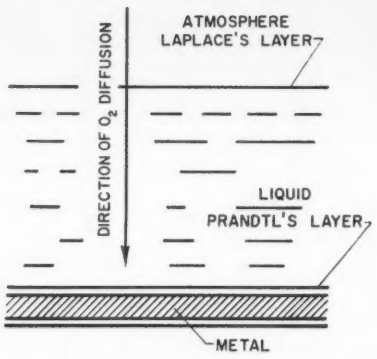


**Figure 129—Oxygen diffusion from atmosphere to metal.**

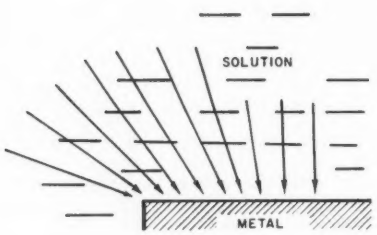


**Figure 130—Diffusion paths at the edge of a metallic plate (the edge itself is covered). (Tomashov.)**

tated by stirring or by convection currents. Oxygen diffusion is directed toward edges of metal plates as well as perpendicular to the surfaces; oxygen can pass to the plate from the side also —all possible diffusion paths are utilized, Figure 130.

Assume that on the metal surface there is a cathodic region which for the sake of simplicity is considered to be round. The volume of liquid through which oxygen diffusion takes place toward the cathode can be schematically represented as a trunkated cone of an angle $\phi$ and with a base of the thickness $\delta$ equal to that of the Prandtl's layer (see Figure 131).

The rate of oxygen diffusion, $A_D$, to the cathodic region depends on the coefficient of diffusion D, on the difference of concentrations $C - C_o$, on the area of the inclusion $f_K$ and on the thickness of the immovable layer $\delta$. If the side paths for the diffusion at the edge of the cathodic inclusion must be accounted for, then the perimeter of the inclusion, $\sqrt{\pi f_K}$ should be considered.

The expression for the rate of diffusion is then:

$$A_D = D\,(C - C_o)\left[\sqrt{\pi f_K} \cdot \tan\phi + \frac{f_K}{\delta}\right] \qquad (62)$$

If it can be assumed that the resistance to diffusion is concentrated almost entirely in the Prandtl's layer, and is negligible in the bulk of the liquid and in the Laplace's layer, then the concentration difference will be that between the concentration $C_o$ at the metal surface and the concentration C at the outer surface of the immovable layer, Figure 131.

The higher the oxygen concentration in the solution and at the outer surface of the Prandtl's layer, and the lower the concentration at the metal, the greater is the rate of diffusion.

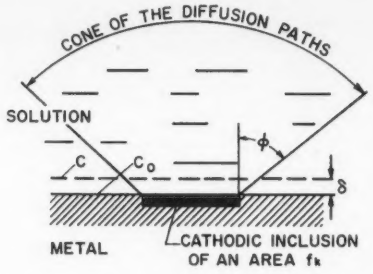


**Figure 131—Oxygen diffusion scheme for a cathodic inclusion (Tomashov).**

When the cathodic areas are large, then their total perimeter is in general small in comparison with the total area, and the term $\sqrt{\pi f_K} \cdot \tan\phi$ in the equation (62) can be neglected. Then the latter becomes

$$A_D = D\,(C - C_o)\frac{f_K}{\delta} \qquad (63)$$

When there are many small cathodic areas, the sum of their perimeters is large in comparison with the total area, and this term no longer can be neglected. In the limiting case, when the cathodic area is very small, the rate of diffusion depends mainly on the total inclusion and the term $\frac{f_K}{\delta}$ can be neglected. If the corrosion process is limited by the rate of oxygen diffusion, the corrosion current in the microcells must be proportional to the diffusion rate.

On the basis of the above considerations, the equation for the corrosion current in a corrosion cell with cathodic depolarization can be written:

$$I = KD\,(C - C_o)\left[\sqrt{\pi f_K}\tan\phi + \frac{f_K}{\delta}\right] \qquad (64)$$

As with the hydrogen depolarization process, the condition for the oxygen depolarization process occurring at a certain rate is

$$E_A < E_{O_2} - \eta' \qquad (65)$$

(i.e., the anodic potential must be lower than the cathodic potential minus the overvoltage for the reaction of oxygen reduction under given conditions.)

The overvoltage for oxygen reduction varies with the current density just as does the hydrogen overvoltage. Hence, in the equation the overvoltage must be obtained for a definite current density. The choice of current density is determined by the minimum corrosion rate of interest.

The majority of practically important corrosion processes proceed under conditions of "oxygen starvation" (i.e., with an oxygen deficiency at the metal surface); if oxygen were present, the cathode could use it in much greater quantities. But oxygen is supplied by diffusion so slowly that it is all used up at the cathodic surface and the process is controlled mainly by the rate of diffusion to the cathode.

It would be in order at this time to examine the corrosion current (or the rate of corrosion) as a function of corrosion cell resistance. It is most convenient to examine the part played by the electrical resistance of a cell with oxygen depolarization by means of a model, which permits changes of the

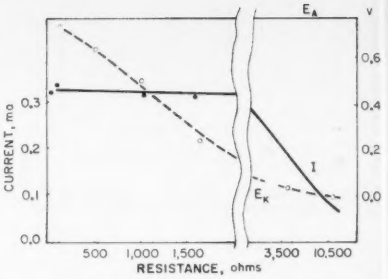


**Figure 132—Variations of current I and of anodic ($E_A$) and cathodic ($E_K$) potentials versus resistance changes of a Cu/Zn cell in 3 percent NaCl (Akimov, Vrucevitch and Clark).**

internal and the external resistance, and, at the same time, of the current and of the anodic and cathodic potentials. The results of investigation with a Cu/Zn cell in a 3 percent NaCl are given in Figure 132.

The abscissa axis represents the total resistance of the cell, which is equal to the sum of the external and the internal resistance. The ordinate is the current, which is, as usual, proportional to the corrosion of the anode. This investigation shows that the current is independent of the resistance in a wide range of changes of the latter, from very low to very high values (i.e., the current curve is a horizontal line.) Only at very high values of resistance does the current begin to drop hyperbolically. Thus, there is an apparent deviation from Ohm's law.

Measurements of the anodic and cathodic potentials show that the anodic potential remains practically constant, when the resistance changes, whereas the cathodic potential changes greatly. It appears that the independence of the current from the resistance is connected with the circumstance that when the resistance is increased, the cathodic potential increases in a positive direction; the resulting increase of the potential difference just compensates for the increase of resistance. This can be explained by the limiting influence of the rate of oxygen supply to the cathodic surface which controls the whole process. There is so little oxygen in the solution that it is used up immediately after it reaches the cathodic surface (i.e., it is reduced by the electrons coming from the anode, to become a hydroxyl ion.)

The same conclusion was reached in the discussion of the Evans diagram for processes with oxygen depolarization (section 3 of this chapter). It is only when the resistance becomes very large, and the potential difference is close to the initial value, that the current starts to decrease. The cathodic potential does not then increase any more in the positive direction, since it has reached the limit—the initial value of the cathodic electrode potential.

The following experiment is instructive: 0.1 percent of hydrogen peroxide is introduced into a 3 percent NaCl solution, thus greatly increasing the amount of oxidizer. It is well known that $H_2O_2$ decomposes easily at the metal surface with the formation of active oxygen. In this case the oxygen supply to the cathode will no longer retard the process; presumably, the electrical resistance is now the controlling factor. The current then changes with the resistance increase according to Ohm's law—i.e., a

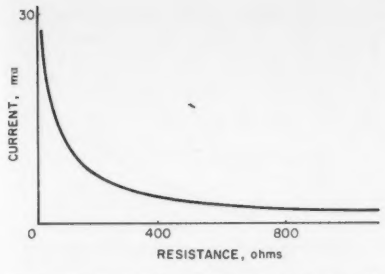


Figure 133—Current in a Cu/Zn cell in a 3 percent NaCl + 0.1 percent $H_2O_2$, versus resistance (Akimov, Vrucevitch and Clark).

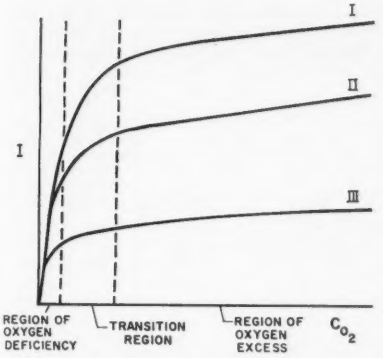


Figure 134—Schematic presentation of the curves current of a cell versus oxygen concentration. The Curves I, II, III are for different cathodes (Akimov).

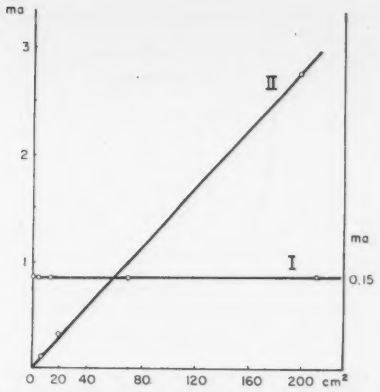


Figure 135—Dependence of current of Cu/Zn cell in 3 percent NaCl solution, on anodic (I) and on cathodic (II) areas. (Akimov, Vrucevitch and Clark). I—Area 1 cm² (right scale). II—Area 1 cm² (left scale).

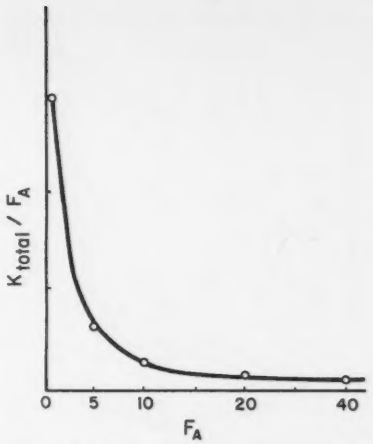


Figure 136—Relative corrosion versus anodic area. (Akimov, Vrucevitch and Clark.)

hyperbolic curve will result (see Figure 133).

Another remarkable outcome of the fact that the total rate of a corrosion process is controlled by the oxygen supply to the cathodic areas, is the essential independence of the current (and of the rate of corrosion) from the anodic potential.

The following experiment was performed. The current was measured in cells with a copper cathode. Anodes were zinc, cadmium, lead. The initial potentials of these metals differed considerably one from another in the NaCl solution: $E_{Zn}$ — 0.77V, $E_{Cd}$ — 0.53V, $E_{Pb}$ — 0.32V.

The results of the experiment showed that in spite of the various initial anodic potentials the current was almost the same in all these cells. The explanation is again the same: by changing the anodic material, there is no corresponding change in the rate of the cathodic process which is connected with oxygen diffusion to the cathode. The same conclusion was reached by considering a typical Evans diagram for real processes (Section 3).

Concerning the influence of the cathodic material on the current in the cell, the following can be said. When there is an oxygen difficiency in the solution and the oxygen supply to the cathode is the limiting factor, the cathodic material should not affect the current of the corrosion cell, and therefore, the total rate of the corrosion process. When there is an excess of oxygen, the difference in the rate of oxygen consumption at the cathode, or the difference in overvoltage for the cathodic reaction of oxygen reduction is noticeable, and current depends on the cathodic material.

Figure 134 shows schematically the changes in current of a corrosion cell I in relation to the oxygen concentration in the solution. With the increase of concentration of $O_2$ the current increases first very steeply, since in this range the oxygen supply is limiting the total rate of the process. Here the curves for different cathodes (I, II, III) coincide (i.e., the current is the same for different cathodes, and so is the rate of corrosion.) At a certain oxygen concentration in solution, the curve starts to bend; in this transition range the effect of the cathodic material is already noticeable, although the influence of oxygen concentration is still quite pronounced. Finally, the slope of the curves becomes small, and the current practically independent of the $O_2$ concentration. In this region the nature of cathodic material will be of great importance, since the oxygen supply does not control the total rate of the process (the curve for different cathodes are different).

It is important, finally, to determine how the areas of the cathode and of the anode influence the current, as was already discussed for processes with hydrogen depolarization. Relations observed here are also connected with the oxygen concentration of the solution.

Experiments with models show that the large increase of the anodic area does not affect the current. The horizontal line on the diagram in Figure 135 (for a constant cathode area) shows the independence of current and corrosion rate of anodic area. It should be kept in mind, however, that while the total current and the total corrosion do not increase with the increase of anodic area, the relative corrosion rate or current per unit of anodic area is changing, of course, corresponding to the anodic area.

The dependence of current density $\frac{I}{F_A}$ and of relative rate of anodic destruction $K_{total}/F_A$ on the anodic area, is represented in Figure 136.

The independence of current and corrosion rate from the anodic area is also the result of insufficient oxygen supply at the cathode. In increasing the anodic area there is no interference with oxygen diffusion, which determines the total rate of the process. The situation is different when the cathodic area is increased. In this case the amount of oxygen arriving at the cathode per time unit is proportionally increased. It would be expected, therefore, that there would be an increase of the current when the cathodic area is increased. Experiments confirm this expectation. The results of experiments with a Cu/Zn cell are given in Figure 135. They show that the current increases approximately linearly with the cathodic area.

When the cathodic area is very large, the relationship is more complicated and cannot be expressed by a straight line. The influence of anodic and cathodic areas for processes with oxygen depolarization, that are controlled by the oxygen diffusion rate, was established theoretically in a discussion of the Evans diagram for real processes in section 3.

Beside the processes regulated by the oxygen depolarization, there are many processes that are connected with both the oxygen and the hydrogen depolarization (mixed processes). A number of important processes such as corrosion of aluminum in neutral solutions, belong to these mixed processes. In this particular case, the process is regulated mostly by the oxygen depolarization. But there are mixed processes where both the hydrogen and the oxygen depolarization are of about the same importance. Finally, in some processes with hydrogen depolarization, the oxygen depolarization must be taken into account.

### 6. Theory of Microcells[8, 10, 12, 14, 19, 20]

Numerous experimental data confirm qualitatively the idea of de la Rive, that the microelements are the basis of the corrosion process. Actually, the impurities in metals in most cases accelerate corrosion considerably, if under the given conditions they can form effective cathodic regions. This applies mostly to processes with hydrogen depolarization. For corrosion processes with oxidizing depolarization the situation is more complicated, as will be seen later; the evaluation of the role of microelements is connected with some difficulties.

A review will now be made of some of the experimental data for processes with hydrogen depolarization. Figure 137 reproduces the results of the well known work by Vondrachek and Isaak-Krichko concerning the influence of al-

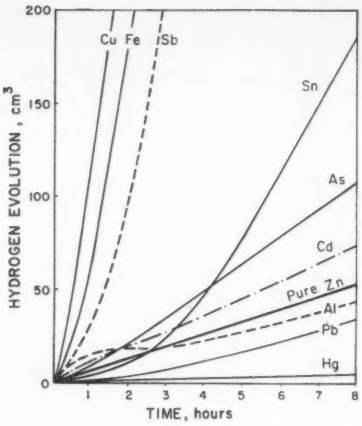


Figure 137—Influence of addition of 1 percent of various metals on corrosion of zinc in 0.5N $H_2SO_4$ (Vondrachek and Isaak-Krichko).

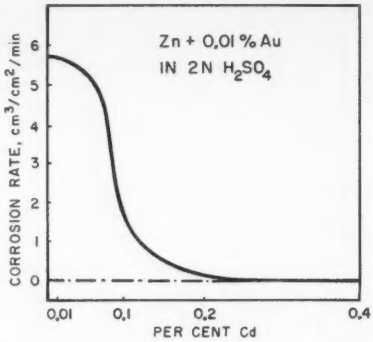


Figure 138—Influence of Cd addition on the rate of dissolving of the alloy Zn + 0.01 percent Au in 2N $H_2SO_4$. The rate for pure zinc under the same conditions is 0.04 cm³/cm² per minute (Straumanis).

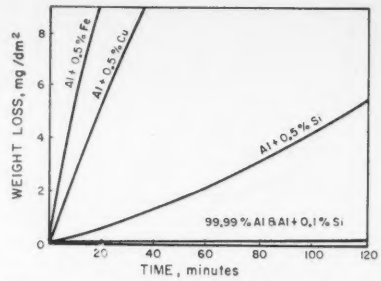


Figure 139—Effect of alloy additions to aluminum on corrosion in 20 percent HCl (Kado).

**TABLE 14—Influence of Alloy Additions to Aluminum Corrosion in 2N HCl (Straumanis)**

| Material | Rate of Corrosion Measured by $H_2$ Evolution in cm³/cm² Per Hour |
|---|---|
| Al 99.998% | 0 |
| Al 99.998% + 0.1% Fe | 2 |
| Al 99.998% + 0.5% Fe | 200 |
| Al 99.998% + 0.1% Cu | 1.5—15 |
| Al 99.998% + 1% Cu | 10.5—150 |

**TABLE 15—Influence of Admixtures in Iron on Corrosion Rate in 1N NaCl (Palmaer)**

| Material | Corrosion Rate, $H_2$ Evolution cm³/cm² Per Hour |
|---|---|
| Grey iron, 3.8% C, 1.3% Si | 8.7 |
| Iron wire, 0.11% C, 0.01% Si | 1.1 |
| Soft iron, heated in $H_2$, 0.02% C, 0.01% Si | 0.11 |
| Electrolytic iron, heated in $H_2$, 0.01% C, 0.01% Si | 0.09 |

**TABLE 16—The Rate of Corrosion for Different Grades of Iron in HCl at 25 C with Stirring (Centnerszwer and Straumanis)**

| Material | Reagent | Rate of Corrosion Measured by $H_2$ Evolution Three Hours After the Beginning of Experiment, cm³/cm²h |
|---|---|---|
| Commercial iron | 4N HCl | 6 |
| "Kahlbaum" iron | 4N HCl | 0.3 |
| "Kahlbaum" iron | 8N HCl | 12 |
| Carbonyl iron | 11.4N HCl (concentr.) | 0.18 |

loying elements on the corrosion of zinc in sulfuric acid. These authors have worked with zinc that was not very pure, and the impurities in the original metal somewhat complicated the picture.

It follows from the diagram that Cu, Fe, Sb greatly accelerate the dissolution of zinc in sulfuric acid. Sn, As and Cd have a much smaller effect, while alloying with Al, Pb, Hg does not accelerate, but, on the contrary, decelerates dissolving of zinc in $H_2SO_4$. The data concerning Cd are contradictory due, probably, to various amounts of impurities in the original zinc used by different workers. When zinc is contaminated by gold, the rate of corrosion is greatly increased. For instance, the rate of corrosion of pure zinc in 2N $H_2SO_4$ is 0.04 cm³/cm² per minute (measured by hydrogen evolution). The same zinc with 0.01 percent Au corrodes with a rate of 5-6 cm³/cm² per minute in the same acid. When to this zinc, contaminated with gold, cadmium is added, the rate of corrosion drops sharply (see Figure 138).

This phenomenon is caused, probably, by the formation of some intermetallic compounds between cadmium and gold having high overvoltage. As a result, the effect of the cathodic inclusions in zinc is greatly diminished, with a corresponding decrease of the corrosion rate. Even a small amount of cadmium practically eliminates the harmful influence of gold additions. Addition of small amounts of Hg has a similar effect.

The effect of alloying with Fe, Cu, Si on the corrosion of aluminum in 20 percent HCl is shown in Figure 139. The diagram shows that alloying with Fe and Cu enhance the corrosion greatly, whereas Si has a much smaller effect.

Recently more accurate measurements were made by Straumanis (see Table 14). It can be seen from this table that the addition of iron has a particularly strong influence on the corrosion of aluminum in 2N HCl. Copper also greatly accelerates the corrosion of aluminum, but it requires some time before the full effect takes place.

The influence of purity of iron on its corrosion rate in 1N HCl is shown in Table 15. The ordinary commercial iron with 0.12 percent total impurities corrodes approximately 10 times faster than soft or electrolytic iron with 0.02-0.03 percent total impurities. Table 16 gives the results of other investigations with iron. Here the difference between the impure and the pure iron is even greater.

Numerous experiments with other metals also demonstrate that in most cases impurities sharply reduce the chemical stability of metals for processes that are controlled by hydrogen depolarization. To do this, the impurities must form effective cathodic regions in metal (i.e., regions with a more positive potential and lower overvoltages than the metal itself under given conditions).

A quantitative proof of the theory of microelements appears very desirable. If the rate of corrosion for some typical metals could be calculated from electrochemical constants for metal and solution, the confirmation of the calculations experimentally would be considered a good proof. Such an attempt was made in the beginning of this century by Palmaer, together with Erickson-Auren. Palmaer's starting point was de la Rive's theory of microelements, which employed basic facts concerning the electrochemistry of galvanic elements available in the second half of the nineteenth century.

Assume that there are n microelements per 1 cm² of the surface of a metal corroding in an electrolyte. One can express for each microelement the current i, for a potential difference V and a resistance R.

$$i = \frac{V}{R} \qquad (66)$$

The sum of the currents from all microelements from 1 cm² surface is obiously

$$\Sigma i = \frac{V}{R} \cdot n \qquad (67)$$

It is not possible at present to measure the resistance of a single microelement. Palmaer introduces therefore a new quantity—"the resistance capacity" C, defined by

$$R = \frac{C}{k} \qquad (68)$$

where k = electric conductivity of the electrolyte.

The meaning of C becomes clearer when one observes that

$$R = \frac{1}{k} \cdot \frac{l}{g} \qquad (69)$$

where $l$ is some average path of the current between the electrodes, and g is some average cross-section of solution between the cell electrodes. Then:

$$C = \frac{l}{g} \qquad (70)$$

Substituting R from (68) in (66):

$$i = V\frac{k}{C} \qquad (71)$$

$$\Sigma i = n\,V\frac{k}{C} \qquad (72)$$

Next, Palmaer expresses the potential difference of a microelement as the difference between anodic and cathodic potentials. For the cathodic potential, Palmaer takes the sum of the equilibrium potential of hydrogen $E_H$ under the

specific conditions and of the hydrogen overvoltage at the cathode $\eta$; for the anodic potential—that of a normal electrode potential of the metal $E_M$ according to Nernst.

$$V = (E_H + \eta) - E_M \qquad (73)$$

so that the current for a microcell

$$i = \left[ (E_H + \eta) - E_M \right] \cdot \frac{k}{C} \qquad (74)$$

and the current from 1 cm² surface

$$\Sigma i = \left[ (E_H + \eta) - E_M \right] \cdot \frac{K}{C} n \qquad (75)$$

According to Faraday's law, one can derive from the current the rate of metal dissolution by introducing a factor f which contains the Faraday constant, the atomic weight of the metal, and the valency of metallic ions entering the solution:

$$K \text{ gr/cm}^2 \text{ per hour} = f\Sigma i = f\left[ (E_H + \eta) - E_M \right] \cdot \frac{K}{C} n \qquad (76)$$

Palmaer considered C as the only unknown in his equation. This value can be neither calculated nor determined experimentally. However, C can be evaluated indirectly, if all other quantities in (76) are known, by measuring k. Furthermore, if the value of C for a given metal does not change under changing conditions, this value of C, once determined by the above method, can be used for calculation of the corrosion rate in other cases (i.e., in different media, at different temperatures, etc.).

Palmaer and Erickson-Auren applied their equation to the case of zinc containing lead as cathodic inclusions. The value of C was determined by dissolving zinc in 1N HCl. The rate of dissolution of zinc in HCl of various concentrations and in solutions of $H_2SO_4$ was calculated, and then determined experimentally. The experimental and the calculated results were found to agree fairly well.

The Palmaer formula was subjected in 1925-1930 to a thorough criticism, particularly by the Latvian scientists Centnerszwer and Straumanis. These workers have shown that Palmaer's formula cannot be correct, and that the agreement of experimental and calculated values was coincidental.

To begin with, it was established that the addition of lead does not produce effective cathodic inclusions in zinc. Hence, the corrosion rate was determined not by these inclusions, but by some other impurities in metal. Yet Palmaer had used the hydrogen overvoltage on lead. This alone casts doubt on the reliability of the calculation.

It was shown further, that Palmaer's equation cannot be correct because:

1. The hydrogen overvoltage at the cathode depends on the current density at the microcell; the overvoltage, however, is considered a constant in the Palmaer equation.

2. The anodic potential of the microcell cannot be considered equal to the normal potential of a given metal. The concentration of metallic ions at the metal surface may vary considerably, depending on the conditions. Besides, measurements have shown that anodic polarization makes the anodic potential more positive.

3. The internal resistance of a microcell cannot be considered constant. The composition of the solution, the areas and position of the microcells change during corrosion. These factors affect the resistance of the microcells.

4. It is not permissible to use a value of C, found experimentally under one set of conditions, for calculation of the rate of other corrosion processes.

Thus far mention has been made only of the main sources of errors in the Palmaer equation. What remains correct in this formula is the application of Ohm's law and of the Faraday's law to corrosion processes. However, the significance of Palmaer's work should not be underestimated, since the application of electrochemical laws to the corrosion of metals was a definite forward step at that time.

Straumanis suggested, as an improvement on Palmaer's formula the following equation:

$$K \text{ gr/cm}^2 \cdot \text{hour} = f \cdot \eta \left( \frac{E_k - E_A}{R} \right) \qquad (77)$$

In this equation $\eta$, $E_k$, $E_A$, and R are variables. The Straumanis formula does not permit, of course, quantitative calculations, and is only a mathematical formulation of applicability of Ohm's and Faraday's laws to corrosion processes.

In chapter III (sections 5, 7 and 8), the fundamentals of the modern theory of microcells were presented. It should be remembered that the conception of a microelement is now considerably broader; beside the "classical" microelements of the type: base A—inclusion B, microelements of the film-pore type, and those with electrodes of the same metal, which are in different physical conditions (chapter II, section 6) are encountered just as frequently.

The equation of corrosion process that has the broadest application is the equation (34).*

$$I' = \frac{V^\circ}{P + R} = \frac{E^\circ_k - E_A}{P_k + P_A + R}$$

It should be kept in mind, however, that this equation is only qualitative in nature. In it simple linear relations between the potential and the current are assumed, whereas by introduction of factor f, containing the Faraday constant, one can obtain the rate of corrosion (i.e., the material consumption of the anodic regions):

$$\frac{dK}{dt} = \frac{f}{F_A} \cdot \frac{E^\circ_k - E^\circ_A}{P_k + P_A + R} \qquad (78)$$

For a logarithmic relationship, considerably more complicated expressions can be suggested. It is doubtful, however, whether they could be used for actual calculations, because a number of complicating circumstances (such as deviation of the actual overvoltages from those measured under given conditions, changes in the relative anodic and cathodic areas, composition changes in the electrolyte at the electrodes, the influence of corrosion products, etc.) cannot be quantitatively considered.

In many cases of corrosion processes with oxygen depolarization, the rate of corrosion is almost independent of the total area of the cathodic regions. This appears to be in disagreement with the theory of microelements, as well as with the regularities established on models (section 5).

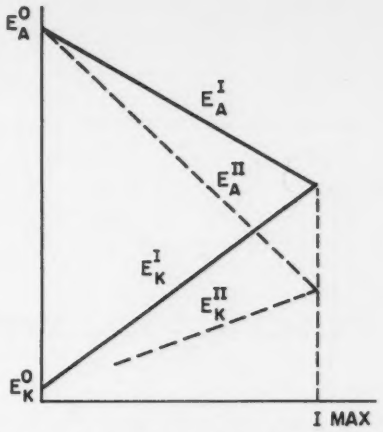


**Figure 140—Evans' diagram showing that the maximum corrosion current does not change when, with the increase of $F_K$, simultaneously $F_A$ is decreased, with a corresponding change of polarization (Akimov).**

For instance, investigations have shown that pure zinc corrodes in neutral solution in the presence of oxygen about as fast as does an impure zinc. The same is true for nitric acid where the process goes with oxidizing depolarization. However, in acids, where zinc corrodes with hydrogen depolarization, the rates of corrosion for pure and impure zinc differ by a factor of several hundreds. The same applies to iron. Pure iron corrodes, under conditions of oxygen depolarization, about as fast as commercial iron, even cast iron. Needless to say, the impure zinc has many more cathodic inclusions, as does the impure iron. The question arises as to why under the conditions of oxygen depolarization this difference is not as noticeable as it is in a model where the increase of the cathodic area produces a proportional increase of the corrosion current. This discrepancy created the opinion that the electrochemical theory is applicable only to processes with hydrogen depolarization, whereas the processes with oxygen depolarization are of a purely chemical nature. This opinion is, however, unsupportable.

There are several reasons why the regularities observed on models are not applicable to corrosion of microelements. When in the corrosion process the cathodic and the anodic depolarizations are about equally important, changes of the cathodic area (and a corresponding decrease of the anodic area, as for the microelements $F_A + F_k = \text{const.}$) may not change the maximum value of the corrosion current. This can be shown with the Evans diagram (Figure 140). The polarization curves obtained before the cathodic regions were increased, are denoted by I, those obtained after the increase by II.

Another reason for the above discrepancy is the fact that the cathodic regions for the processes with hydrogen and for those with oxygen depolarization might be completely different. If, for instance, in a corrosion process with hydrogen depolarization, the inclusions of cementite $Fe_3C$ in iron may act as cathodic regions, this may not be true in a process with oxygen depolarization. In the latter case, instead of inclusions

* Equation (34) is included in Part 2 of G. V. Akimov's Chapter 3 "Electrode Potentials." This paper was published in *Corrosion*, **11**, 515t (1955) Dec.

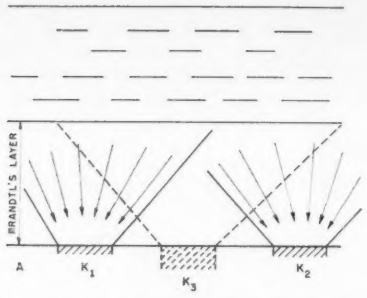


Figure 141—Diagram demonstrating the utilization of the diffusion paths by the cathodic inclusions (Tomashov).

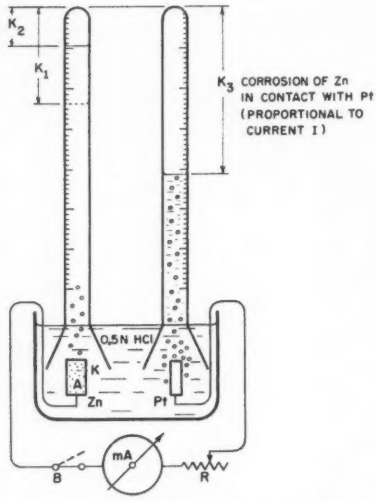


Figure 142—Measurement of the positive difference effect with Zn in 0.5N HCl. The difference effect $\Delta K = K_1 - K_2$; $K_3 = f_2 I$ (Akimov).

of $Fe_3C$, the protective oxide film that is preserved in a neutral solution may act as a cathode. Consequently, in some processes, impurities of one kind may act as cathodes whereas in other processes, inclusions of other kinds or protective films may act as dual cathodes.

There is, finally, a third very important reason for the discrepancy, that was discovered quite recently. The possibilities for oxygen diffusion might be exhausted even with a small number of cathodic regions; further increases of the number of cathodic regions does not increase the amount of oxygen flowing to the cathodic area in unit time. This can be clarified by Figure 141.

Assume that there are two cathodic inclusions $K_1$ and $K_2$, on a certain metallic surface. The oxygen diffusion to each inclusion is given by the cone of the diffusion paths in the immovable liquid layer. It can be seen from the diagram that even with two cathodes there is some interference, because the diffusion paths of one intersect the diffusion paths of the other. If on this surface there is one more cathodic inclusion $K_3$, there will be a corresponding cone of diffusion paths. However, the diffusion paths are already used up by the two other inclusions. Hence, the introduction of an additional cathode would add practically nothing as far as the increase of oxygen supply to the cathodic regions of the metal is concerned.

This explains why there is a discrepancy between the regularities established with models, and a number of actual corrosion cases with oxygen depolarization. Thus, there is no reason to abandon the electrochemical theory of processes with oxygen depolarization. It is only necessary to take into consideration the relative positions of the microcells with respect to diffusion of oxygen.

Several recent papers[12, 19, 20] discuss certain cases of corrosion (that of very pure metals and of amalgams) on the basis of homogeneous electrochemical dissolution. It is assumed that the metal-solution interface is perfectly homogeneous, and that the anodic and the cathodic processes occur at random, in a statistical sense, on the whole surface having the same value of electrode potential. From this standpoint, one cannot speak of anodic and cathodic areas, nor of a potential difference between the cathode and the anode. This approach has some advantages for calculations in certain cases. It is believed, however, that the theory of microcells might be used consistently even in these extreme cases. The surface of a liquid amalgam, or of a very pure metal is actually not perfectly uniform: there are atoms and atomic groups differing in their energy levels from those in the neighboring sections. It is quite reasonable to expect that the variations in the state of these different elements of the surface can produce some potential difference, however small. The distance between the anodic and the cathodic regions are very small in these cases and consequently the resistances of the microscopic microcells are also very small. Hence, small potential differences may produce considerable currents, and a noticeable corrosion. The possibility of a direct chemical interaction between the metal and the solution cannot be denied in a number of cases. Oxygen in the solution might even directly oxidize the metal, but only where this process has thermodynamic or kinetic advantage over electrochemical oxidation.

### 7. The Difference Effect[7]

Among corrosion processes with hydrogen depolarization, there is one important phenomenon, the so called difference effect. Consider the following experiment, Figure 142. Two electrodes are placed in a solution. A contact is established by means of a switch B through a galvanometer mA and a resistance R. Platinum forms the cathode, and impure zinc, which corrodes rapidly in 0.5N HCl solution, is the anode. Above each electrode a graduated test tube is placed to measure the amount of hydrogen evolving at each electrode.

In the beginning of the experiment the cell is disconnected, and the destruction of the zinc electrode proceeds because of the working of its own microcells.

Hydrogen evolving in the test tube above zinc, is the result of discharge of hydrogen ions at the microcathodes which are formed by the more electropositive inclusions in the zinc. The rate of hydrogen evolution in this case will be denoted by $K_1$. This is the rate of zinc corrosion measured by the volume of hydrogen evolving in unit time, when zinc is being corroded only by action of its own mircocells.

Then the circuit zinc-platinum is closed, and zinc forms the anode, platinum the cathode. Hydrogen evolution will be observed both at the platinum and at the zinc. The total amount of hydrogen evolving at both electrodes in unit time will be considerably larger than in the former case. The fact that hydrogen continues to evolve at the zinc signifies that the microcells are continuing their work after an external cathode is connected. However, the rate of hydrogen evolution will now be much smaller; the latter will be denoted by $K_2$.

Thus, $K_2$ is the rate of zinc corrosion measured by the volume of evolving hydrogen, as a result of working of microcells, but in the presence of an external electrode.

The rate of zinc corrosion in the presence of a large external platinum electrode shall be denoted by $K_3$. The total corrosion of zinc, with the external cathode, is given by the sum $K_3 + K_2$ (i.e., is equal to the rate of zinc corrosion due to the presence of the large, external cathode plus the rate of zinc corrosion due to its own microcells in the presence of the external cathode).

Evidently $K_3$ is much larger than $K_1$. It is found however, that in most cases $K_1$ (the rate of zinc corrosion without a contact with the external cathode), is larger than $K_2$ (the rate of zinc corrosion due to the microcells in the presence of the external cathode).

The difference between $K_1$ and $K_2$ is called the difference effect:

$$\Delta K = K_1 - K_2 \qquad (79)$$

The difference effect is connected with the interaction between the microcells and the macrocell (platinum-zinc represents the macrocell while the microcells are located on the zinc). The positive difference effect shows that the macrocell reduces the work of the microcells.

The difference effect is the larger, the higher the current in the macrocell. Since the current I in the macrocell is proportional to $K_3$, then:

$$\Delta K = f_1 I = f_2 K_3 \qquad (80)$$

where $f_1$ and $f_2$ are constants.

Thus, the more energetically the macrocell is working, the smaller is the work of the microcells on the corroding metal.

There are, however, a few cases where the opposite is true. For instance, the microcells on Duralumin in NaCl solution work even more energetically where the external cathode is connected. In this case $K_2$ is larger than $K_1$, and a negative difference effect exists.

The positive difference effect is observed mostly in corrosion cases with hydrogen evolution, when the protective film on the metal surface is not very effective.

In the case of zinc in hydrochloric or sulfuric acids, the protective film on zinc apparently does not greatly influence the rate of corrosion process: it is destroyed at the commencement of the process. When the protective film remains intact during the corrosion process and noticeably affects the rate of corrosion, one often has the negative, instead of the positive, difference effect.

The negative difference effect can be demonstrated by the following simple

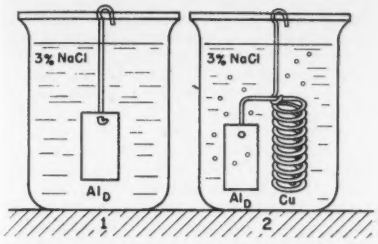


Figure 143—Qualitative demonstration of the negative difference effect in Duralumin ($Al_D$) in NaCl. No hydrogen bubbles can be observed on Duralumin without a contact (Drawing No. 1) with the copper spiral. When Duralumin is connected with the copper (Drawing No. 2) hydrogen bubbles are evolved not only on the copper (cathode), but also on the Duralumin (anode). $\triangle K = K_1 - K_2$ (Akimov).

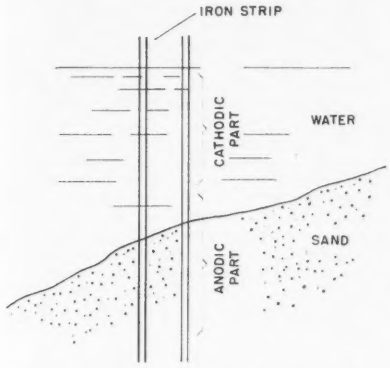


Figure 144—Formation of a cell with differential aeration in an iron strip (Akimov).

experiment: A sheet of aluminum, or still better Duralumin, is placed in a neutral solution of sodium chloride (Figure 143). The sheet corrodes slowly, as exact measurements show, with both oxygen depolarization (i.e., consumption of oxygen from the solution), and hydrogen depolarization (i.e., slow evolution of hydrogen). Hydrogen is evolving so slowly that it is difficult to observe it (visually). However, when the aluminum sample is connected to a large cathode, for instance, a spiral made from a copper wire, the evolution of hydrogen can be observed visually not only at the copper spiral, but at the Duralumin sample. This experiment shows that the local microcells are working considerably faster in the presence of an external cathode, so that it is possible to observe the evolution of hydrogen bubbles of the Duralumin sheet.

In alkaline solutions, the protective film on Duralumin is dissolved, and is not of great importance. In these solutions Duralumin shows not a negative, but a positive difference effect.

The question as to the explanation of the positive and of the negative difference effect was much discussed. It seems that the positive difference effect is connected with potential changes when an external cathode is connected. The positive difference effect can be deduced for microcells with a noticeable internal resistance, from the rule for multi-electrode systems (Chapter VI).

### 8. Electrochemical Cells with Differential Aeration[18]

There is one special type of galvanic cells for processes with oxygen depolarization that is often of practical importance—the so-called differential aeration cells.

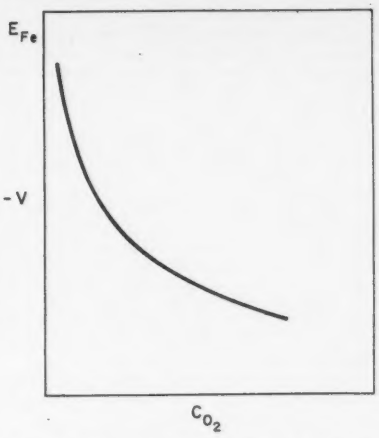


Figure 145—Iron potential versus oxygen concentration in a neutral solution.

Consider an iron strip imbedded partly in sand. The corrosion process will go with oxygen depolarization at the expense of oxygen diffusing from the air to the iron surface (Figure 144).

Obviously, the access of oxygen to the upper part of the strip is easier than to the lower, because the diffusion paths in the upper part are shorter and besides, the sand in the lower part forms an obstacle for oxygen penetration to the metal. Under these circumstances, the metal surface, more easily accessible to the oxygen, will become the cathode; the metal surface less accessible will become the anode. This is the result of changes of electrode potential under the influence of oxygen at the metal surface. The changes of iron potential as a function of oxygen concentration in a neutral solution are shown in Figure 145. The higher the oxygen concentration in the solution surrounding the electrode, the higher the positive iron potential. This undoubtedly is connected with the increase of stability of the protective film on the iron surface in the presence of oxygen.

It is now clear why the upper part of an iron sheet, which is more accessible to oxygen and where the concentration of oxygen at the metal surface is higher, becomes cathodic with respect to the lower part, which is less accessible to oxygen.

This results in a galvanic cell in which the part of the iron surface receiving more oxygen becomes cathodic, and the part less accessible to oxygen becomes anodic. Between the anodic and the cathodic parts a current is produced, and corrosion commences due to the work of this electrochemical cell. Naturally, it is the anode that is being corroded (i.e., the part of the surface where the oxygen supply is less abundant). The surface receiving more oxygen becomes cathodic and does not undergo corrosion. This is the differential aeration cell (i.e., a cell resulting from different rates of oxygen supply to the different parts of the metal surface).

A very good example of a cell with differential aeration is represented by a drop on the surface of an iron sheet, Figure 146. When a drop is placed on

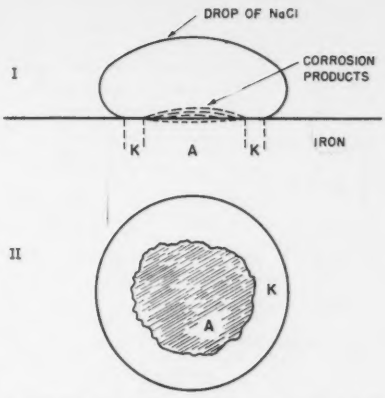


Figure 146—Corrosion under the drop resulting from the effect of a different aeration cell. I—the side view; II—the top view (Evans).

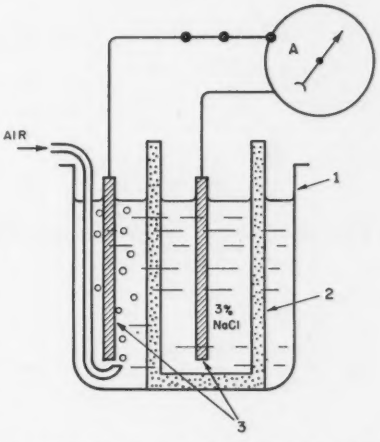


Figure 147—Experiment proving the formation of a differential aeration cell (Evans). 1—the outside container, 2—porous cylinder, 3—iron specimens.

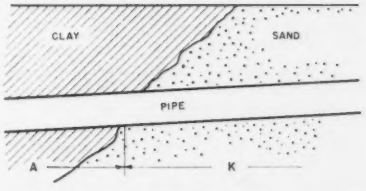


Figure 148—Formation of a differential aeration cell in an iron pipe laid in the ground with sections of different permeability for air (Evans).

a clean iron sheet, there will be observed, after some time, a few spots of rust under the drop. The corrosion process starts in some regions of the drop—probably in the least protected sections of the protective film. However, after a while corrosion will stop at the periphery of the drop, and it will be intensified at the center of the drop. This distribution of the corrosion under the drop can be easily explained by the formation of a differential aeration cell. Oxygen easily reaches the iron under the peripherial parts of the drop; it has to follow a longer path to reach the central part. Hence, the peripheral zone becomes the cathodic zone, and the central zone becomes the anodic one; a cell

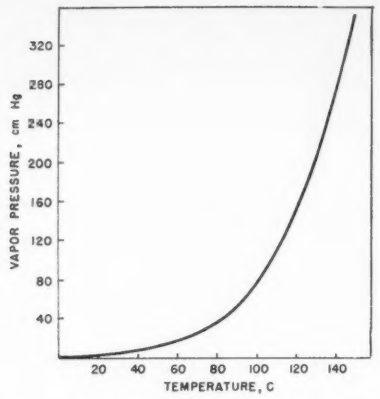


**Figure 149—Pressure of water vapor saturating air versus temperature.**

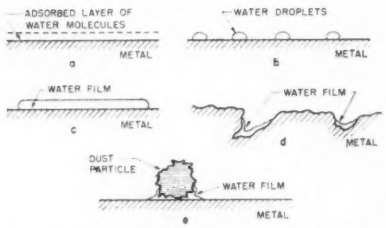


**Figure 150—Condensation of moisture on the metal surface (Akimov).**

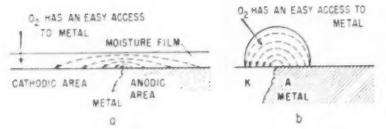


**Figure 151—A scheme for corrosion in a moisture film (a) and in a drop (b) (Akimov).**

is formed, and consequently, the destruction of the central anodic section under the drop will proceed, whereas the peripherial section will remain almost untouched.

The following experiment is of a more quantitative nature. A porous cylinder is placed in a container; both are filled with a 3 percent NaCl solution. Two identical iron specimens are immersed in the solution, one in the cylinder, the other outside the cup; the specimens are connected through a galvanometer (Figure 147). Since the specimens are identical, there should be no potential difference between them, and the galvanometer will indicate no current. However, when a tube is placed in the outer container and air or oxygen is passed through the tube, a current between the two iron electrodes will start immediately. The direction of the current indicates that the sheet around which oxygen is blown is the cathode, and the sheet in the inner cylinder is the anode. The more oxygen is blown through the higher the current in the cell.

One often encounters cells of this kind in practice, particularly when iron corrodes in neutral electrolytes. For instance, these phenomena appear in the corrosion of the lower part of a gas tank which is partially immersed in water. Corrosion develops under the water, at a certain distance from the water line, whereas the parts adjacent to the water line are not touched by corrosion.

This is understandable from the standpoint of differential aeration, since the oxygen supply to the latter parts of iron sheet of the gas tank is relatively ample, and to the lower parts smaller. Thus, a differential aeration cell is formed. It should be noted that in general, differential aeration cells appear in stagnant liquids.

One encounters similar examples in underground corrosion. If a pipe is laid partly in a soil easily aerated, and partly in a soil through which air can pass only with difficulty, such as clay, Figure 148, a differential aeration cell is created; the pipe placed in the clay soil will be attacked. The pipe located in the sand will corrode very little.

Corrosion resulting from a differential aeration cell also might occur with metals other than iron.

### 9. Corrosion Processes in a Moisture Film

The amount of water vapor in grams per 1 $mm^3$ of air is called the absolute humidity. At a given temperature, the air can hold water vapor in an amount not exceeding that producing saturation. The higher the temperature, the greater the amount of water vapor the air can maintain without saturation. Figure 149 shows the relation between the air temperature and the amount of water vapor saturating the air. The ratio of the amount of water vapor present in the air to that saturating the air at the given temperature, is called the relative humidity and usually is expressed in percentages. The increase of the amount of water vapor above the amount saturating the air leads to formation of water in small drops (fog), slowly condensing on the walls of the container and on other bodies in contact with the vapor.

When the air not saturated with water vapor (i.e., having a relative humidity less than 100 percent) is cooled, then at a certain temperature saturation will be reached, and the condensation of water will begin in the form of a fog. A smooth, metallic surface in an atmosphere with a relative humidity less than 100 percent is covered with only a monomolecular adsorption water film, Figure 150a.

When the temperature drops, or when the amount of water vapor in the air is increased, the dew point will be reached, and condensation of water on the metal will begin in the form of minute droplets (Figure 150b). The metal becomes "moist." Depending on the nature of the metal, condition of the surface and degree of saturation of the atmosphere with water vapor, the size of the droplets may be larger or smaller. When the condensation is continued, the droplets may unite and form a thin continuous water film. Initially this will occur on isolated areas of metal but finally, the whole surface will be covered with a layer of water, Figure 150c. The metal will become wet. If the metal surface is rough, or if there are hard particles of dust on the metal surface, coal etc., or porous areas of the protective film and corrosion products, then condensation may start in pores, cracks and crevices before the dew point is reached and form a layer of water at least several molecular layers thick (see Figure 150 d and e).

The gases of the atmosphere ($N_2$, $O_2$, $CO_2$), and gaseous admixtures in the air such as $SO_2$, nitric oxides, HCl, etc. will dissolve in the water droplets, and thus the droplets and films of moisture will consist not of pure water, but of solutions of the various gases in the water. $SO_2$, nitric acids, HCl are easily soluble in water and may appear in noticeable concentrations in the moisture film, even if their amount in the air is not large. In the sea air there are particles of sea salt, and hence chlorides and, to some extent, sulfates may appear on the metal surface and dissolve in the water droplets. The air of rural districts is contaminated only slightly, but the air in the cities and industrial centers might contain considerable amounts of various corrosion producing gases. Particularly noticeable is $SO_2$, coming from the smoke from the burning of coal containing sulfur. It has been calculated that in London the atmosphere receives daily 1000-2000 tons of sulfuric acid. $SO_2$ can be oxidized in air to $SO_3$ which will form $H_2SO_4$ with water. In some cases, this process is accelerated by the catalytic action of the metal itself (nickel, for instance).

In the vicinity of chemical plants the air may contain HCl, $NH_3$ and other gases in addition to $SO_2$. The atmosphere of industrial centers may contain considerable amounts of dust. For instance in Pittsburgh (USA), Liverpool (England) and Duisburg (Germany), the amount of dust has been estimated as 50 tons per 1 $km^2$ per month. The composition of dust in the city of Pittsburgh was as follows

| | |
|---|---|
| Organic Substances | 35 percent |
| $Fe_2O_3$ | 19.5 percent |
| Insoluble Minerals | 38.8 percent |
| Soluble Salts (mainly sulfates) | 9.2 percent |

Similar to the case of the immersion of metal in a solution, a corrosion process may start under the droplets or moisture film. The droplets or the film act as electrolyte. The corrosion process in a moisture film and in a droplet are presented schematically in Figure 151a and 151b.

Consideration now will be given to the conditions for electrolytic corrosion in a water droplet, or in a moisture film on a metal surface. A thin moisture film or a water droplet is a small hindrance for the diffusion of the air oxygen to the metal surface through the electrolyte. Thus, in the case of corrosion under the moisture film there is a very intensive oxygen depolarization of the cathodic regions of the metal. The easy access of an energetic oxidizer (i.e., of oxygen from the air), is responsible for the fact that the processes of atmospheric corrosion are mostly those with oxygen depolarization, even in the case of action of a relatively acid medium (for instance, of dissolution of $SO_2$ in the moisture film) on active metals (iron, zinc, aluminum).

When the amount of the electrolyte is small as in the case when it is distributed in small drops or thin films, the electrical corrosion current encounters a high resistance. Hence, even with large potential differences between the metal surface and the electrolyte, the current is small for very small drops or very thin films.

The resistance of the electrolyte is smaller when the drops or the film thickness are larger, and the current is increasing.

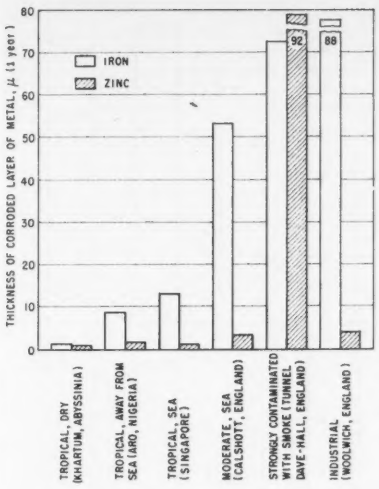


Figure 152—Comparison of action of atmospheres of various kinds on iron and zinc (Hudson).

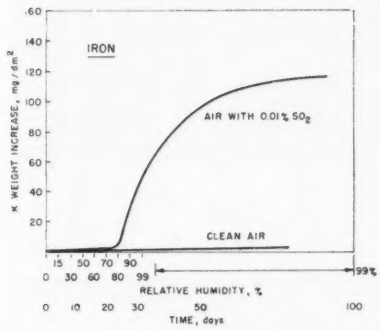


Figure 153—Influence of humidity on atmospheric corrosion of iron in clear air contaminated with $SO_2$ (Vernon).

The dissolution of sulfur oxides, nitric oxides, HCl, salts such as NaCl, $(NH_4)_2SO_4$, etc., in the moisture film increases the conductivity of the electrolyte and may thus considerably increase the corrosion currents. Consequently, substances dissolved in the moisture film might increase the rate of corrosion not only because of the decreased pH value of the electrolyte, or because of the presence of ions destroying the protective film, but also because of the increased electrical conductivity of the moisture film.

The higher the electrical conductivity of the film (i.e., the higher the specific conductivity of the electrolyte), and the thicker the film, the larger the distance influenced by the nonuniformity in the metal itself and by contacts with other metals. Usually the influence of the nonuniformities and of the contacts or corrosion in a moisture film is noticeable only within a short distance (fractions of a millimeter to a few millimeters, for good conducting moisture films).

### 10. Atmospheric Corrosion[38]

Atmospheric corrosion is one of the most common types of corrosion of metals. Large engineering constructions such as bridges, steel framework of buildings, various machines, means of transportation, military equipment, communication wires, etc., often suffer from atmospheric corrosion. Furthermore, the fight with atmospheric corrosion is a constant source of worry in warehouses for metal products, and in machine fabricating plants, because the atmospheric corrosion spoils expensive parts, even before they can be assembled, if no precautions are taken. As it was pointed out above, atmospheric corrosion is a special case of electrochemical corrosion occurring under a moisture film. There are various kinds of destruction caused by atmospheric corrosion. Among them are the typical cases of uniform corrosion and of corrosion spots (particularly in the beginning stages of corrosion development), as well as of pitting and intercrystalline corrosion.

The beginning stage of atmospheric corrosion often is connected with the so-called tarnishing of metal. This stage is observable only on carefully polished parts and samples. Tarnishing is caused by the appearance of numerous microscopic regions where corrosion started, or by formation of a continuous film of corrosion products.

Tarnishing is important not only as an indicator of atmospheric corrosion, but also in itself. Metallic reflectors, metallic products of architecture, many household items, automobile trim, etc., should remain shiny during the whole service life, and tarnishing may cause the need for replacement of these items.

It was pointed out in the previous section, that the presence of substances dissolved in a moisture film could affect the rate of atmospheric corrosion. Experiments show that the rate of corrosion of typical metals actually is different in atmospheres of various kinds.

The differences are even larger for atmospheric corrosion in different regions. Figure 152 gives the results of tests with iron and zinc in natural atmospheres of different kinds. It should be noted that, in the majority of atmospheres, zinc is usually considerably more stable than iron. Only in an atmosphere heavily contaminated by smoke, the stability of zinc is as low, and is even lower, than that of iron. In a similar way, the composition of the atmosphere and the humidity are the most important factors in atmospheric corrosion. The presence of $SO_2$ is particularly unfavorable.

The influence of humidity on corrosion of iron in a clear air and in air with 0.01 percent admixture of $SO_2$ is depicted in Figure 153.

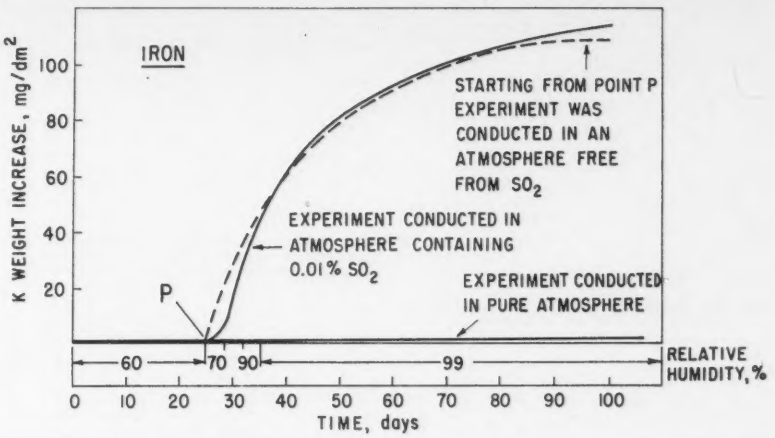
IRON
STARTING FROM POINT P EXPERIMENT WAS CONDUCTED IN AN ATMOSPHERE FREE FROM SO2
EXPERIMENT CONDUCTED IN ATMOSPHERE CONTAINING 0.01% SO2
EXPERIMENT CONDUCTED IN PURE ATMOSPHERE
P
K WEIGHT INCREASE, mg/dm2
RELATIVE HUMIDITY, %
TIME, days

Figure 154—Influence on the rate of corrosion of iron of transferring a sample (after the critical humidity was reached) to an atmosphere free from $SO_2$ (Vernon).

The humidity was gradually increased during the experiment. There are two scales on the abscissa axis, the time scale and the scale of relative humidity. It can be seen from the diagram that corrosion proceeds in the clean air very slowly (the slope of the curve is very small), even at high humidity. The presence of only 0.01 percent $SO_2$ increases the rate of corrosion greatly. A sharp increase of the rate of corrosion occurs only after a certain humidity is reached, the so-called critical humidity. Below this point, the presence of $SO_2$ affects the corrosion very little. Small amounts of $SO_2$ increase corrosion mainly by reducing the protective qualities of the natural protective film on the metal surface. This statement can be proved by the experiment shown in Figure 154.

A sample of iron was exposed to an atmosphere containing 0.01 percent $SO_2$ as the humidity of the air was increased. When the critical humidity point was reached, the sample was transferred into clean air. The sample corroded just the same, as did a sample that was kept all the time in the atmosphere with $SO_2$. This shows that the film on the sample was destroyed before the corrosion had reached a high rate, because of the presence of $SO_2$. The poor protective qualities of the film were not apparent before, because the rate of corrosion below the critical humidity was small.

An increase of $SO_2$ content up to 0.1 percent in air accelerates the rate of corrosion still further. The increase of relative humidity and the presence of $SO_2$ in air affects other metals and alloys similarly. Figure 155 shows the rate of corrosion vs time and increased humidity in air containing 0.01 percent $SO_2$.

Other corrosion-producing gases such as $H_2S$, $Cl_2$, nitric oxides, also accelerate the corrosion of many commercially important metals in the atmosphere. The corrosion of copper is greatly increased when $NH_3$ is present in the atmosphere.

Experiments with $CO_2$ showed that this gas not only does not increase the corrosion of iron in the atmosphere, but actually decreases it.

Beside gaseous impurities, some hard particles suspended in the air (dust) are of great importance. If a metal sample in a moist atmosphere is protected from the dust by placing it in cotton tissue,

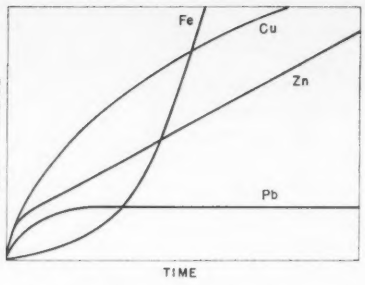


Figure 155—Curves of corrosion versus time for several metals in the atmosphere.

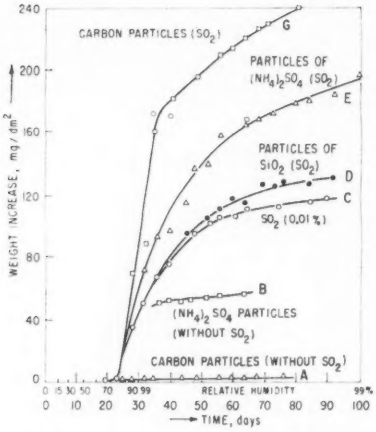


Figure 156—Influence of carbon particles, $SiO_2$ and $(NH_4)_2SO_4$ on corrosion of iron, with and without $SO_2$ (Vernon).

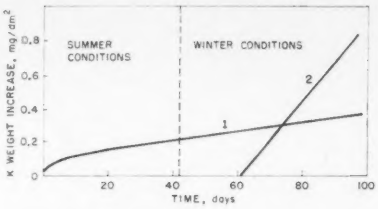


Figure 157—Comparison of curves: atmospheric corrosion versus time, for samples that started to corrode (1) in summer, and (2) in winter (Evans).

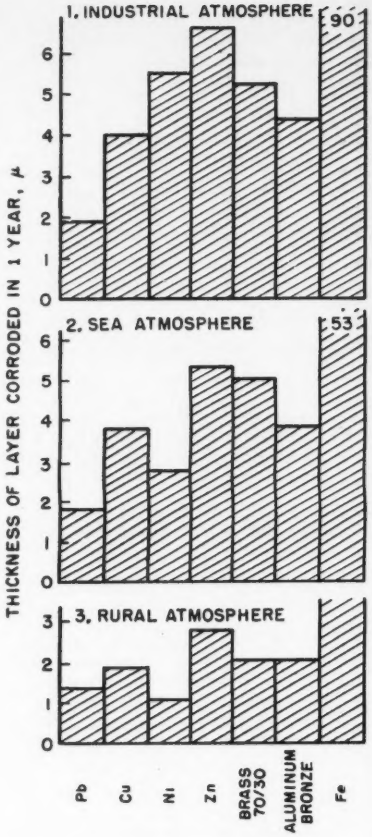


Figure 158—Comparison of the action of different atmospheres on some commercially important metals (Hudson).

it corrodes much slower than the control sample that is not protected. However, now all particles are dangerous to the same extent. The components of dust may be divided into the following groups:

1. Particles that produce corrosion by themselves. Examples of this include particles of salts $(NH_4)_2SO_4$, NaCl.

2. Particles not corrosion-producing by themselves, but readily adsorbing from the air corrosion producing gases, particularly $SO_2$. Particles of carbon belong in this group.

3. Particles that neither produce corrosion nor adsorb harmful gases from the air. To this group belong small sand particles (mostly $SiO_2$).

Figure 156 shows the influence of carbon particles of $(NH_4)_2SO_4$ and of $SiO_2$ in the presence and in the absence of 0.01 percent $SO_2$ on iron corrosion. It follows from the diagram that carbon particles accelerate the corrosion only in the presence of $SO_2$, that particles of quartz are inactive and do not accelerate the corrosion and that particles of $(NH_4)_2SO_4$ are active by themselves, although not as much as $SO_2$ in air. These data demonstrate that a rapid increase of the rate of corrosion in the presence of contaminations in air begins at a relative humidity less than 100 percent and that therefore a relatively thick film of moisture may be formed under these conditions on the metal. This is connected with the hygroscopic properties of the corrosion products. The thin layer of sulfate deposited on metal adsorbs a considerable amount of moisture from the air, and thus a relatively thick film of moisture can be formed. Carbon particles as well as some salt particles in the air also are hygroscopic, and upon their deposition on the metal, a moisture film appears after a while.

The action of vapors of sulfurous acid ($H_2SO_3$) upon nickel is a remarkable example of the influence of hygroscopic corrosion products. If a nickel plate is placed in a desiccator above a solution of sulfurous acid, the sample soon becomes wet, and intensive corrosion is initiated. $SO_2$ oxidizes on the nickel surface to $SO_3$, with the formation of $H_2SO_4$. The latter adsorbs moisture strongly, and a light green liquid containing the nickel sulfate begins to drip from the nickel plate. Zinc over concentrated hydrochloric acid soon also becomes wet, since the zinc chloride formed is very hygroscopic.

If, as a result of atmospheric corrosion, a continuous film of corrosion products that has protective qualities is formed, the equations deduced for the relationship between the film thickness and time (Chapter 1) are applicable in this case also. If the film has very weak protective properties, then the amount of corrosion products will be a linear function of time.

Studies of zinc corrosion in a moist atmosphere below saturation have demonstrated that only a very thin lower layer of oxides has protective properties whereas the larger part of the film formed by the corrosion products is very porous and does not represent an effective barrier for the action of the active corrosion medium.

The rate of atmospheric corrosion depends sometimes to a great extent on the initial conditions of exposure. In the Figure 157 the corrosion curves are shown versus time for copper samples that were tested in similar conditions (city atmosphere), but their corrosion was started at different seasons of the year. Sample 1 started to corrode in summer. The corresponding curve has the shape of a parabola indicating the protective properties of the film formed. Sample 2 started to corrode in winter. It can be seen that the corrosion for this sample proceeds faster than for sample 1, and the relationship is not parabolic, but linear. The different behavior of these two samples is explained by a larger $SO_2$ content in winter, and the film formed under this condition had weaker protective properties. The film formed in summer was protective to such an extent that the advent of winter with its higher $SO_2$ content in the air could not essentially change the quality of the film.

Aluminum and aluminum alloys possess a good protective film and are well preserved in an atmosphere that is not very contaminated. However, particles of chlorides in air (see atmosphere) may produce heavy corrosion, often of an intercrystalline nature. The skin covering of airplanes operated in the extreme north without suitable maintenance sometimes suffered heavy intercrystalline corrosion. In such cases the Duralumin sheets, in spite of externally good appearance, could be easily broken into small pieces with bare hands. Magnesium and magnesium alloys in atmosphere of high humidity may start to corrode very fast.

In discussing the behavior of metals in an atmosphere, one has to consider the influence of rain. The rain, besides thoroughly wetting the surface, may dissolve and wash away the protective film reducing its thickness and its protective properties. Sudden temperature changes may also destroy the film as a result of stresses set up by unequal expansion or contraction. Finally, the film may fall off the metal surface in large pieces. It was pointed out previously that the air contamination by $SO_2$, HCl and other active gases, as well as by coal dust, is one of the main reasons for the heavy atmospheric corrosion in cities and in industrial centers. Taking into account the enormous amount of metals destroyed by atmospheric corrosion, government organizations should take measures for the prevention of atmospheric pollution. Primarily this ap-

plies to power plants, central heating stations, chemical plants; these installations must provide means for removing harmful gases and coal dust, especially $SO_2$, from the combustion produced. The comparative corrosion stability of the most important metals in atmospheres of three types is given in Figure 158.

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**Any discussions of this article not published above will appear in the June, 1959 issue**

Research in Progress

# Mechanisms of Wash Primer Actions

By E. R. ALLEN*

## Introduction

A RESEARCH program has been underway at Rutgers University for approximately three years to investigate the mechanism of the changes which take place with time in the reactive type of Wash Primer WP-1, MIL-C-15328A. This composition, a mixture of phosphoric acid, zinc tetroxychromate, and polyvinyl butyral (PBVA) resin, typically compounded in ethyl and butyl alcohols, possesses unusual merit as a metal conditioner in connection with corrosion inhibition by means of organic coatings. It has an unfortunate tendency, though, to deteriorate with time; it was for this reason that a study of mechanisms involved was made.

The Rutgers program, employing the techniques of physical chemistry, organic chemistry, and polymer chemistry has been concerned with: (a) the fundamental chemistry of the pigment, (b) possible reaction of the phosphoric acid with the resin in the WP-1 mix, and (c) the changes in the WP-1 mix with time.

A phase rule study of the system, $ZnO \cdot CrO_3 \cdot H_2O$, at 25 C showed a series of compositions within the range of acceptable pigment properties in which the solubility varied inversely as the basicity.[1] The specified zinc tetroxychromate, $5ZnO \cdot CrO_3 \cdot 4H_2O$, of high basicity and low solubility, is viewed as a saturated solid solution of ZnO in $CrO_3$ (or of ZnO in $ZnCrO_4$ or in $2ZnO \cdot CrO_3 \cdot H_2O$), therefore capable of definition as a chemical species. At the other extreme of the range of acceptable pigment properties—higher solubility and lower basicity—the *compound* $2ZnO \cdot CrO_3 \cdot H_2O$ (or $Zn(OH)_2 \cdot ZnCrO_4$) is indicated; between these points the solubilities and basicities vary continuously.

These compositions are best viewed as a series of solid solutions. This picture of high basicity more satisfactorily explains the reaction in the mix between phosphoric acid and the pigment, and what is probably more important, suggests the possibility of eventually preparing a pigment better suited to meeting the requirements of WP-1, once these are more clearly understood.

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## Reactions of Acid With Resin

Two reactions of the phosphoric acid with the resin in the mix were viewed as possible: (a) esterification and (b) hydrolysis of the acetal linkage.[2] If (a) took place the resulting products would show the reduced viscosity curve characteristic of a polymer with ionizable groups linked to the chain (i.e., a polyelectrolyte). This type of measurement is recognized technique in polymer chemistry. That is, the reduced viscosity, specific viscosity/concentration of a polyelectrolyte, *decreases* with increasing concentration, whereas in the case of a neutral polymer this value *increases* with concentration. No polyelectrolyte behavior was shown, although a phosphoric ester prepared synthetically did give the predicted type of curve. In the study of (b) it was shown that some actual hydrolysis does occur in compositions simulating those existing in WP-1, although this action is relatively slight, representing an equilibrium condition. However, it was clearly shown that a shifting of this equilibrium in favor of aldehyde formation takes place in the presence of $Cr^{+3}$ salts. This is a reaction which would be expected to increase with time in WP-1 compositions and thus cannot be safely disregarded.

## Fractionation of Mix

The fractionation of the mix at regular time intervals by especially refined centrifuging techniques, effecting reasonably sharp separation of the pigmentary material from the resin solution, was developed. Resin recovery and purification was accomplished through dilution of the centrifugate with a non-solvent, then washing with water in a two-layer system to provide for the extraction of the water soluble inorganic ions, $zinc^{+2}$, $chromium^{+3}$, $phosphate^{-3}$, and $chromate^{-2}$.

The recovered resins showed in all cases the behavior of neutral polymers (i.e., the reduced viscosity increased linearly with concentration.) The analytical evidence that zinc, chromium and phosphorus are incorporated in the resin molecule does not necessarily prove that polyelectrolytes are formed: the amounts may be too small for detection or neutral complexes may have been formed. The *intrinsic* viscosity (the reduced viscosity graph extrapolated to zero concentration) showed a marked decrease at the outset (i.e., before deterioration had begun, followed by a gradual decrease with time, with no evidence of any abrupt change or break.) Analyses of the resin by conventional methods showed changes that were scarcely beyond experimental error, additional evidence that the cleavage of the actual linkage is relatively small.

Analytical determinations on the changes with time in the centrifugate contribute to the knowledge of the fate of the inorganic materials. Phosphoric acid decreases relatively rapidly, as does $zinc^{+2}$, but the proportion that exists in the form of acid phosphates should be determined more accurately. $Chromium^{+3}$ does decrease but does not disappear completely in two weeks. The amount of $chromium^{+3}$ is very small, although that united with the resin may be appreciable.

There are good theoretical reasons for viewing the existence or non-existence of polyelectrolytes as of significance in the stability of WP-1. The methods under study in this program, while tedious, give promise of clearing up this point as well as of the above cited behaviors of inorganic ionic material—all phenomena believed to be of importance relative to the mechanism of the deterioration of the WP-1 mix.

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**TECHNICAL PAPERS ON CORROSION WELCOMED**

**Authors of technical papers on corrosion are invited to submit them for review without invitation to the Editor of Corrosion. Write for "Guide for the Preparation and Presentation of Papers" sent free on request to prospective authors.**

# The Corrosion Resistance of Ductile Iron*

By F. L. LaQUE


## Abstract

The internal structure of ordinary grey iron, pearlitic ductile iron, ferritic ductile iron, malleable iron and mild steel are compared. Differences in the amount of carbon present and in the form in which it occurs are responsible for some differences in the corrosion behavior of these materials. This is explained on the basis of the electrochemical reactions which occur during corrosion. As corrosion proceeds, the graphite which is present in the cast materials may accumulate as a graphitic layer on the surface. The adherence and permeability of such graphitic layers and their influence on subsequent corrosion and on galvanic behavior are discussed. Corrosion data in acids, in neutral and alkaline solutions, in sea water, in the atmosphere and underground, in miscellaneous environments, and under conditions involving erosion are presented and interpreted in the light of the principles outlined above. By and large, it is concluded that ductile iron has satisfactory corrosion resisting properties which permit its use where grey iron, malleable iron, or steel are regularly employed. 6.2.2


## Introduction

DUCTILE IRON[1] is a high carbon, cast ferrous material having a composition generally the same as that of grey iron. A small addition of magnesium causes the graphite to take the form of spheriods rather than the conventional flake or plate form characteristic of grey iron. The almost continuous network of flake graphite particles in grey iron is the major factor controlling its mechanical properties and is responsible for its relative weakness and lack of ductility.

Ductile iron, with its spheroidal form of graphite, in which the surface area to volume ratio of the graphite particles is at a minimum, presents a continuous matrix of iron with only minor discontinuities due to the presence of the graphite particles. Thus, a much greater realization of the mechanical properties of the iron matrix, which in actuality is a steel, is achieved. Ductile iron then is a material which enjoys the foundry characteristics of grey iron and mechanical properties similar to those of steel. The structure of the iron matrix can be controlled by compositional variations and heat treatment to produce properties ranging from 60,000 psi tensile strength with high ductility (i.e. over 20 percent elongation), to over 150,000 psi tensile strength with 2-4 percent elongation.

In many cases resistance to corrosion is a minor factor in the choice of the ordinary varieties of ductile iron for a particular use. In others which can benefit from the protective effects of its corrosion products and galvanic protection from associated steel, it may be a really important factor in its use. Where corrosion resistance is of even greater concern, an austenitic variety of ductile iron containing 20 percent or more nickel is chosen. These highly alloyed ductile irons will not be dealt with in this paper. Attention will be concentrated on the corrosion resistance of ordinary ductile iron. This is important enough in most applications to warrant this review.

## Electrochemical Effects

The internal structure of a metal can have a considerable effect on the corrosion reactions and especially on the distribution and path of the corrosive attack, and on the nature and adherence of the corrosion products. It is useful, therefore, to start this discussion by reference to Figures 1-4 which show, respectively, the internal structures of ordinary grey iron and ductile iron, pearlitic and ferritic ductile iron, mild steel and malleable iron. For purposes of this discussion, the points to be observed in comparing these structures are:

**About the Author**

**FRANK L. LaQUE—Vice President and Manager of the Development and Research Division, The International Nickel Co., Inc., New York. Mr. LaQue has been prominent in the promotion of corrosion studies and the dissemination of corrosion-control data for many years. A past-president of NACE, he is a member of and has held responsible positions in many other technical organizations concerned with corrosion. He has been the recipient of many honors for his work in corrosion and has published numerous technical papers both in the United States and abroad.**

1. The difference in shape of the graphite carbon in grey iron and ductile iron as shown in Figure 1 and especially the distribution of the graphite particles as well separated discrete particles in the ductile iron as compared with overlapping and interconnecting flakes in the ordinary iron.
2. The difference in the matrix surrounding the graphite spheres in the pearlitic as compared with the ferritic ductile iron as shown in Figure 2. In the former, the matrix is principally pearlite and in the latter, principally ferrite.
3. The difference between all the cast irons and mild steel where, in the latter, all the carbon is in a combined form and usually exists as pearlite as shown in Figure 3, whereas in the cast irons a large portion of the carbon exists as graphite in one shape or another.
4. The similarity of ductile iron to malleable iron (Figure 4) with respect to the distribution of the graphite particles, even though there are important differences in the composition of the matrix and the shape of the graphite particles.

These differences in the amount of carbon present and the form in which it occurs are principally responsible for observed difference in the corrosion behavior of cast iron and steel. The basic chemical or electrochemical behavior of the iron matrix including any alloying elements in solid solution can be expected to be the same in all the irons and steels. It is, therefore, the reactions involving the matrix, on the one hand, and the carbon in whatever form it exists, on the other, that are of principal importance in accounting for any differences in corrosion behavior that have been observed or may be anticipated.

It is generally agreed that most corrosive environments of practical interest include a liquid containing ions and, therefore, capable of conducting electricity. It also is agreed that the fundamental processes of corrosion involve a flow of electricity between the attacked areas from which current enters the liquid from the metal (anodes) and separated areas (cathodes) in which the current re-enters the metal from the liquid to complete the circuit of electricity that causes the corrosion. In order for this current to flow, there must be a potential gradient in the liquid between the anodes and the cathodes. The greater the potential gradient, the greater will be the amount of corrosion current that can flow and the greater will be the forces that will have to be counteracted if corrosion is to be reduced to tolerable levels. These counteracting forces that generally determine just how fast corrosion will proceed are involved principally in the chemical and electrochemical reactions that occur at the anodic and cathodic surfaces.

In most environments of practical interest in the use of iron and steel, the reactions that occur at the cathodes are more important in determining the rate of attack than those that occur at the anodes. And, since the carbon in the irons and steels, whether it exists as graphite[1] or as carbides,[2,3] is much more noble than the iron matrix, it regularly acts, along with oxide films on the metal surfaces, as cathodes in the corrosion current circuit. Therefore, the activity of these cathodes becomes of prime importance in understanding the corrosion behavior of the materials under consideration.

It is necessary also to be concerned with the two principal electrochemical reactions that occur at corrosion current cathodes. Where the hydrogen ion concentration (acidity) of the solutions and the potential difference between the

★ Submitted for publication December 16, 1957. A paper presented at the Fourteenth Annual Conference, National Association of Corrosion Engineers, San Francisco, Calif., March 17-21, 1958.

(1) Patents on ductile iron are held by The International Nickel Company, Inc. and the material is produced by foundries under a license agreement.

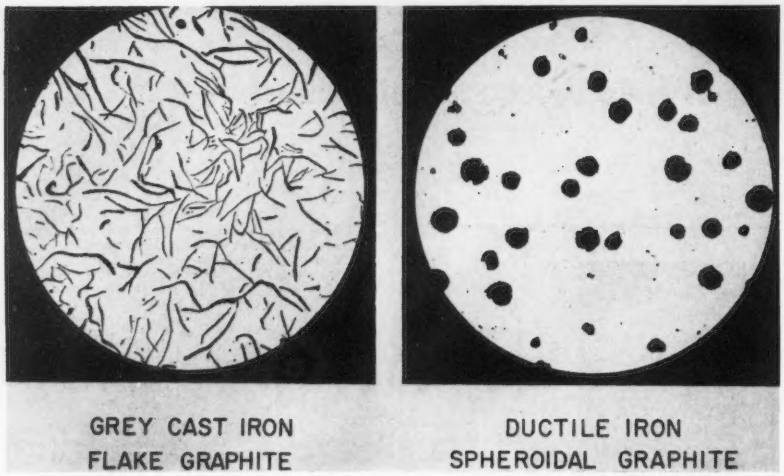
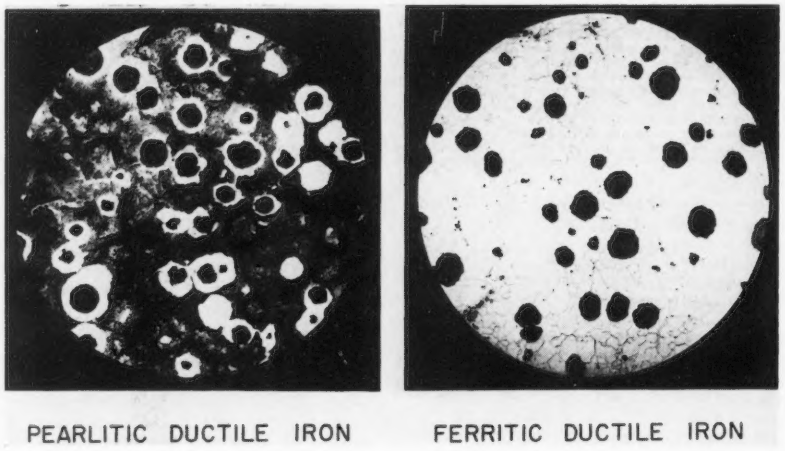



**Figure 1—Photomicrographs of grey iron compared with ductile iron. Original magnification, 250X; actual magnification after reduction for engraving puposes, 145X. Unetched.**




**Figue 2—Photomicrographs of pearlitic and ferritic ductile iron. Original magnification, 250X; actual magnification after reduction for engraving purposes, 145X.**

anodes and cathodes are high enough, the principal cathodic reaction will be the discharge of hydrogen ions and the release of hydrogen as a gas bubbling off the cathodic surfaces. Where the conditions do not permit such hydrogen evolution, the cathodic reactions that must occur if corrosion is to proceed, involve some reaction with oxygen in the solution. This reaction may be visualized either as a combination of discharged hydrogen ions with oxygen to form water or hydrogen peroxide, or a direct reduction of dissolved oxygen to form hydroxyl ions ($OH^-$). In any event, since oxygen is consumed in these cathodic reactions, since the rate of its consumption will determine the rate of corrosion, and since the amount of oxygen available may limit the rate of its consumption, it is evident that the amount of oxygen in a solution often will have a controlling effect on its corrosivity.

It should be understood, also, that other chemicals having an oxidizing effect similar to that of oxygen can replace or supplement oxygen in promoting corrosion by permitting cathodic reactions to proceed. Certain bacteria (e.g., *Sporovibrio desulfuricans*) frequently encountered in substantially oxygen-free soils and waters can participate in cathodic reactions and, in effect, take the place of the missing oxygen in permitting corrosion to go on.

The rates of electrochemical reactions that occur at the anodes and cathodes are proportional to the current density (current flow per unit area). Therefore, the areas of the anodes and cathodes are important. They not only determine the current density when the total amount of current from all anodes and cathodes is fixed, but also influence the total amount of current by establishing the areas of the surfaces that can participate in the electrochemical reactions. For example, the larger the area of a cathode, the greater will be the accessibility of dissolved oxygen to it and the greater will be the amount available for consumption in enabling corrosion to proceed at a substantial rate. It is not difficult, therefore, to understand that where the cathodic reactions control the rate of corrosion, the area of the cathodes becomes very important and that where the area of the anodes is held relatively constant, the rate of corrosion may go up or down directly as the area of the cathodes is increased or decreased. This is pertinent to a later discussion of the differences between the effective area of the graphite in ductile iron as compared with grey iron, and the difference between pearlitic and ferritic ductile iron.

The distribution of the graphite also is important. Since corrosion tends to penetrate along the margins of the graphite particles,[4] the rate and extent of such penetration can be expected to be less when the graphite occurs as discrete spheroids with random distribution, as in ductile iron, than when it exists as interconnected or overlapping flakes, as in grey iron. This will give ductile iron an advantage over grey iron.

Where the acidity of the environment is such that considerable hydrogen evolution can occur, the associated flow of current and the rate of corrosion are usually so high that it is impractical to use a metal that corrodes in this way. Thus, behavior in solutions where the principal cathodic reaction is hydrogen evolution is largely of academic interest.

### Effects of Graphitic Carbon

Since graphite is insoluble in the environments in which any of the cast irons is likely to be used, it is natural that as corrosion proceeds the graphite in the iron will be left as a residue adhering more or less firmly to the as yet unattacked iron beneath. The firmness of the attachment and the compactness or permeability of the graphitic residue are influenced by the strengthening effects of other insoluble constituents of the iron such as carbides, silicious compounds and phosphide eutectic stringers or insoluble corrosion products that may be precipitated within the graphitic corrosion product layer. The graphitic layer with its intermixed insoluble corrosion products, etc., can become so impermeable to the further penetration of corrosive liquids that it will form an excellent protective coating than can stifle any further attack.[1]

Under such circumstances, the cast irons will be much more durable than steel which is unable to protect itself in this fashion.

On the other hand, if the graphitic layer remains permeable to the further penetration of corrosive liquids, the attack on the underlying iron not only will continue but may proceed at a rate accelerated by the galvanic effect of the graphite layer. This graphite layer acts as an enlarged cathode to supplement the other cathodes within the structure of the underlying iron. Where this occurs, the cast iron will corrode much faster than steel.

It is understandable that behavior in any given case will represent the balance between the opposing effects of graphitic corrosion products just discussed and that it is impossible to make any generally applicable statements as to the relative abilities of steel and cast irons to resist corrosion.

It is understandable, also, that the ability of graphitic corrosion products to adhere to the corroded iron surface will vary with the environmental conditions and, possibly, with the structure of the matrix of the iron. Adherence to the point of building up graphitic layers of substantial thickness will not be expected where the surfaces are regularly or frequently subjected to abrasion or erosion as by liquids in sufficiently turbulent flow to remove the graphite particles as fast as they become ex-

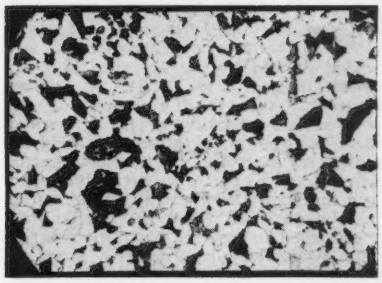


Figure 3—Photomicrograph of normalized and tempered 0.30 C Grade B cast steel. Original magnification, 500X; actual magnification after reduction for engraving purposes, 185X. Etched.

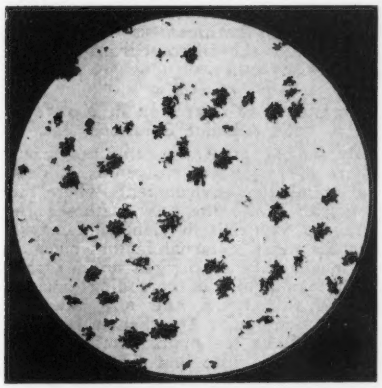


Figure 4—Photomicrograph of malleable iron. Original magnification, 250X; actual magnification after reduction for engraving purposes, 85X. Unetched.

posed. On the other hand, burial in the earth or exposure to liquids in relatively quiet motion will favor accumulation of layers of graphitic corrosion products.

The permeability of such graphitic layers will be reduced by precipitation within them of insoluble iron compounds such as oxides and especially ferric oxide. The conversion of the original corrosion products to insoluble oxides can occur readily in alkaline or neutral solutions and may not occur at all in acid ones. Thus, relatively impermeable and therefore possibly protective graphitic corrosion product layers are most likely to be encountered in neutral and alkaline environments and least likely in acid solutions.

In some instances, the so-called graphitic corrosion of cast iron can proceed until nothing but the graphitic corrosion products remain. These may retain the shape and original volume of the corroded iron object which may, upon casual inspection, appear to have suffered no damage. Since the graphitic corrosion products are much weaker than the iron, the ability of the corroded iron to withstand stresses or carry a load will be reduced very greatly. However, some strength will remain. For example, pipes buried for 24 years in soils in which the original cast iron had been locally converted almost completely to graphitic corrosion products were shown[5] to be still capable of holding liquids under a pressure of 400 lb per sq inch. Similarly long service has been observed in cast iron pipes submerged in and carrying sea water, as for example in an installation at Nice made in 1904 which is still in use today.[6]

A number of controversies exist as

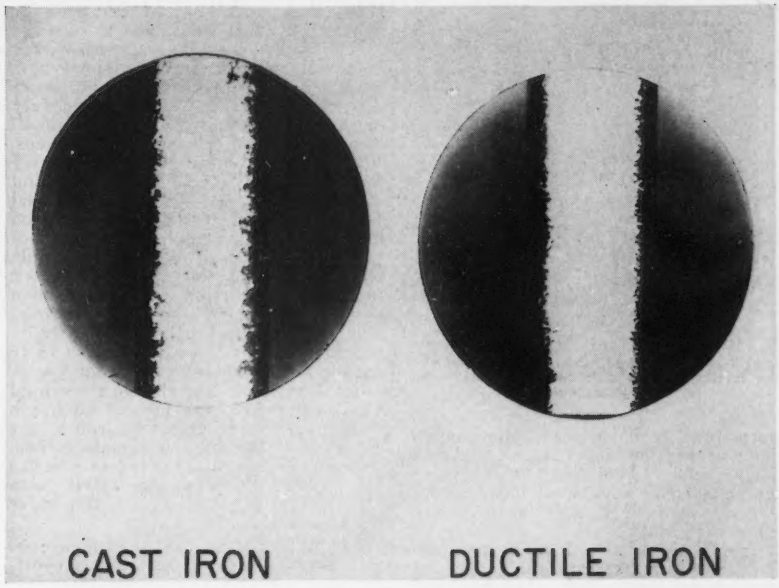



Figure 5—Graphitic corrosion product layers on pearlitic irons. Specimens were 1 x 2 x 0.25 inches in size and were exposed to 15 percent aluminum sulfate at 110 F for 14 days. Original magnification, 7X.

to the relative merits of cast iron and steel as corrosion resisting materials. The variable effects of graphitic corrosion products are largely responsible for this. In some cases they confer complete protection from further attack, and in other cases result in a gross acceleration of attack. These corrosion products under certain circumstances can perform the functions of the original iron. The varying effect of graphitic corrosion products makes it difficult, at this stage, to predict without question whether in any given instance ductile iron will behave like steel or like grey cast iron where the one class of materials is known to behave quite differently from the other.

It has been demonstrated that ductile iron can corrode so as to leave a residual layer of graphitic corrosion products very similar in appearance to the layers that form on grey cast iron. This is illustrated by Figure 5 which shows cross sections of both types of iron with the graphitic layers that developed on each during exposure to a solution of aluminum sulfate in which graphitic corrosion of cast iron occurs.

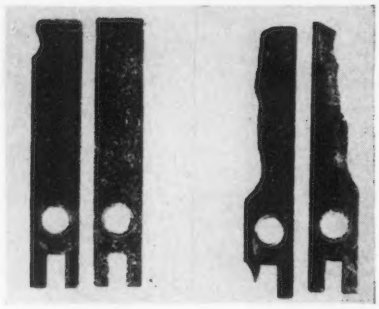
However, questions remain as to whether in particular circumstances the corrosion product layers made up of the spheroidal graphite particles from ductile iron will be more or less permeable than similar layers composed of flake graphite particles from grey cast iron. Questions have been raised also as to the strength of the graphitic corrosion products from ductile iron of low phosphorus content which may not benefit from the reinforcing effect of the phosphide network that is believed to add considerably to the strength of graphitic corrosion products on high phosphorus grey iron.

On the other hand, differences in the strength of graphitic corrosion products are likely to be important only when such corrosion products represent most of what is left of the original iron. Circumstances where such differences in graphite strength will be readily important are not likely to be common. So long as any substantial amount of iron remains unattacked, the superior strength and toughness of the ductile iron itself should be more than sufficient to compensate for any relative weakness of the graphitic corrosion products associated with it and thus enable the ductile iron to retain its mechanical advantages over grey cast iron until corrosion of the irons has been practically complete. Again, with respect to behavior in acid environments where phosphorus and sulfur are known to accelerate corrosion of iron,[2] the lower phosphorus and sulfur content ductile irons may be expected to be attacked less than grey cast irons of higher phosphorus or sulfur content.

Unfortunately, it does not seem possible to undertake accelerated corrosion tests that will predict the normal development of graphitic corrosion products on cast iron under normal conditions of use. Since ductile iron is a relatively new material, there has not been sufficient time to determine what its characteristic behavior will be in those environments, such as soils and waters, where graphitic corrosion is usual for grey iron. Long time tests that will answer these questions are in progress. In the meantime, results of tests already completed show that the chance of satisfactory behavior is good enough to encourage the practical use of ductile iron as a substitute for grey iron, malleable iron or steel, for example, in underground service where the proponents of each of these materials claim advantages over the others.

### Galvanic Behavior

Prior to the acquisition of a layer of graphitic corrosion products, the electrochemical potentials of ductile iron, grey cast iron and steel will be about the same. Measurements in sea water moving at 13 ft per sec showed open circuit potentials for ductile iron of around 0.61 volt versus a saturated calomel half cell. All of these forms of iron can be made



Pearlitic Ferritic

**Figure 6—Appearance of dutile cast iron specimen after rotating bar test at 27 feet per second for 60 days in sea water.**

more noble by alloying with more noble elements such as nickel and copper that can be held in solid solution. Iron containing a small amount of nickel as an alloying element can be made more noble than mild steel by 50 millivolts or so. This potential difference can achieve substantial cathodic (galvanic) protection of alloyed ductile iron when used in electrical contact with an appropriate area of mild steel (i.e., an equal or larger area of the latter as for example in the case of ductile iron heating coils in salt water ballasted cargo spaces on tankers).

Once either grey cast iron or ductile cast iron has acquired a layer of graphitic corrosion products, much more complex galvanic relationships can develop. The graphite layer will exhibit a potential several hundred millivolts more noble than ungraphitized cast iron or mild steel.[1] This will make it cathodic to the underlying iron, to associated mild steel and to any other metals less noble than the graphitic corrosion products. Here, again, the liquid permeability of the graphitic corrosion products will have a large effect on what happens. With a highly permeable layer, the current flowing to it from the underlying iron will cause a shift in its potential (cathodic polarization) to some value between that of the iron and that of the graphite layer. The possible galvanic effect on other electrically connected metals will, therefore, be less than where the graphitic layer is impermeable and subject to polarization only by currents flowing from such other more remote metals. In any case, contact with other less noble metals such as mild steel will reduce the normal corrosion of ductile iron or grey cast iron to the extent that these other metals furnish part of the current required to polarize the graphitic corrosion products to a potential close to that of the iron under the graphitic layer.

In the particular case of heating coils in tankers in services such as transporting Middle East crudes where steel coils are subject to severe pitting of the upward facing surfaces, the presence of graphitic corrosion products on ductile iron may be largely responsible for their superior performance.

**TABLE 1—Tests of Ductile Iron and Grey Iron in 5 Percent Sulfuric Acid Saturated With Air at 30 C (86 F)***

| MATERIAL | CORROSION RATES mdd | ipy |
|---|---|---|
| Unalloyed ductile iron (as cast with pearlitic matrix) | 27,000 | 5.4 |
| Unalloyed ductile iron (annealed with ferritic matrix) | 16,000 | 3.2 |
| Unalloyed grey cast iron (as cast with pearlitic matrix) | 33,000 | 6.6 |
| Unalloyed grey cast iron (annealed with ferritic matrix) | 40,000 | 8.0 |

* Specimens moved at 16 ft per minute for 24 hours.

**TABLE 2—Tests in 3½ Percent Sodium Chloride Solution Saturated With Air at 30 C (86 F)***

| MATERIAL | CORROSION RATES mdd | ipy |
|---|---|---|
| Ductile iron (1.5 percent Ni) (as cast with pearlitic matrix) | 145 | 0.029 |
| Ductile iron (1.5 percent Ni) (annealed with ferritic matrix) | 155 | 0.031 |
| 1.5 percent Ni grey cast iron (as cast with pearlitic matrix) | 135 | 0.027 |
| 1.5 percent Ni grey cast iron (annealed with ferritic matrix) | 130 | 0.026 |
| Unalloyed grey cast iron (as cast with pearlitic matrix) | 180 | 0.036 |
| Unalloyed grey cast iron (annealed with ferritic matrix) | 140 | 0.028 |

* Specimens moved at 16 ft per minute for 7 days.

### Resistance to Corrosion by Acids

While there is little opportunity for practical application of cast irons in strong acid solutions, their performance in such media is of scientific interest, as discussed previously. In addition, there are borderline environments involving weak acid solutions where the behavior in strong acids will provide some indication of the relative merits of the different kinds of iron.

Investigators have reported results of tests in acids which generally show some advantage of ductile iron over grey iron and steel and of ductile iron with a ferritic matrix over ductile iron with a pearlitic matrix.[6, 7, 8]

Tests in 5 percent by weight air-saturated sulfuric acid at 86 F for 24 hours in the Inco Research Laboratory at Bayonne, N.J., yielded the results in Table 1. These results can be accounted for on the basis of the previous discussion of the roles of graphite and carbides in the corrosion of cast iron. Ductile iron would be expected to be superior to grey iron irrespective of the structure of the iron matrix (whether pearlitic or ferritic). This is because with a given mass (weight percent) of carbon, the area of the graphite particles capable of supporting the cathodic reaction of hydrogen evolution (and consequently the corrosion rate) will be much less when the particles approach the shape of spheres than when they exist as flat flakes.

Since the carbides in pearlite can act also as cathodes in the corrosion reaction their elimination by annealing would act further to reduce the total cathodic area and likewise reduce the corrosion rate, as observed with ferritic ductile iron. The nature of the structure of the matrix is much less important with grey iron because of the overwhelming effect of the very large area of the surface of the graphite flakes in grey iron and the greater potential difference between iron and graphite as compared with that between iron and carbides.

While the rate of corrosion of annealed ductile iron is still too high to permit its use in such a strong acid as 5 percent sulfuric, the results of the tests in this medium suggest that when there is to be an exposure to an even weakly acidic solution, ductile iron can be expected to perform better than grey iron and that the greatest improvement will be achieved when the ductile iron is annealed to provide a ferritic matrix. The probable advantage of annealed ductile iron will be greater where there is enough turbulence to remove graphitic corrosion products as they are formed so that the indicated differences in corrosion rates will persist. If graphitic corrosion products should accumulate, the initial differences in corrosion behavior will become less evident and the rates for the different irons will approach each other.

### Resistance to Corrosion in Neutral and Alkaline Solutions

By far the greatest use of cast irons where corrosion is involved is in neutral or alkaline environments where the principal, if not the only, cathodic reaction is oxygen reduction. Under such circumstances, external factors such as the availability of oxygen and its rate of diffusion to the corroding surface through the liquid and any adherent corrosion products or other surface deposits will be the major factors in determining the rate and distribution of corrosion. Internal factors such as structural differences betweeen cast iron and steel and between different kinds of cast iron will have little opportunity to affect corrosion rates. Furthermore the effects of oxide films on the metal surfaces will be similar; consequently all these ferrous materials will be corroded alike, at least in the early stages. The effects of adherent graphitic corrosion products eventually may determine the progress of corrosion of cast irons and result in substantial differences in final behavior as discussed previously.

The similarity in corrosion rates of different irons in neutral or slightly alkaline solutions is illustrated by laboratory tests in 3½ percent sodium chloride with results as shown in Table 2.

Comparing these results with those from the tests in sulfuric acid in Table 1, it will be observed that there were no significant differences amongst the several irons in the salt solution, whereas there were considerable differences in the tests in the acid. Tests in fresh water yielded results generally similar to those in the sodium chloride solution.

### Resistance to Corrosion by Sea Water

Sea water ordinarily is slightly alkaline so that laboratory tests in natural or synthetic sea water regularly fail to show any significant differences amongst the various types of iron.[6, 7, 8, 9] This is particularly the case when the specimens are immersed in the ocean so that an accumulation of marine growths can introduce a barrier to the diffusion of oxygen which is the same for all the irons.

Specimens were immersed in the sea at Harbor Island, N.C., for three years. Both ductile iron containing 1.5 percent nickel, and grey iron were corroded at the same rate as measured by weight losses equivalent to penetration at a rate of about 0.01 ipy. However, the alloyed

ductile iron was pitted less to a maximum depth of 0.033 inch in three years as compared with a depth three times as great, 0.097 inch, for the grey iron. As noted previously, cast iron pipe even after corrosion in sea water may be capable of performing satisfactorily due to the beneficial properties of the graphitic residue.

### Resistance to Erosion

When exposure to sea water, and presumably other neutral or alkaline solutions, involves effects of velocity or turbulence sufficient to interfere with the adherence of corrosion products, substantial differences in the behavior of different irons may be observed. Such differences presumably reflect differences in the abilities of different irons to hold corrosion products in place, as by the keying effects of the teeth-like residual pearlitic carbide particles that may be left on the surface of lamellar pearlitic iron as described by Manuel.[10] This would account for certain observation in tests conducted at Harbor Island for the U. S. Navy Engineering Experiment Station, in which specimens in the form of flat bars attached to the periphery of a non-metallic disc were whirled through sea water at a tip velocity of 27 feet per second for 60 days. Specimens of ductile iron, as cast, with a pearlitic matrix resisted attack much better than the same iron annealed to achieve a ferritic matrix as illustrated by the appearance of the specimens after test shown by Figure 6. Microscopic examination of the specimens after this test revealed that the pearlitic ductile iron specimens had been able to retain an adherent layer of graphitic corrosion products which had shielded the underlying metal from further attack.

No such adherent corrosion products were found on the ferritic specimens. These results suggest that where maximum adherence of graphitic corrosion products would result in protection against progressive attack, as by erosion in the test described, it would be desirable to provide ductile iron with a pearlitic matrix. This also would be helpful where cavitation-erosion is a factor, in line with the general tendency for resistance to such erosion to increase with the hardness of the material. Tests in water using a magnetostriction vibration device for achieving cavitation on the surfaces of the specimens showed that in a six hour test, the cavitation damage suffered by annealed ductile iron with a ferritic matrix and hardness of 162 BHN was almost five times greater than that suffered by the same iron with a pearlitic matrix and a hardness of 255 BHN. Further heat treatment of this iron to achieve a hardness of 356 BHN achieved only a relatively modest (50 percent) further improvement in resistance to cavitation erosion.[11]

The ability of pearlitic ductile iron to resist cavitation erosion in mildly corrosive environments was illustrated dramatically by the performance of a ductile iron impeller in a high speed boiler feed water pump. In this service a ductile iron impeller outlasted 13 percent chromium stainless steel previously used (see Figure 7).

### Resistance to Atmospheric Corrosion

Recently acquired data have supported many practical observations of the superiority of cast irons over ordinary steels in resisting atmospheric corrosion. This advantage is most evident and most useful in the most corrosive atmospheres such as near the sea coast.

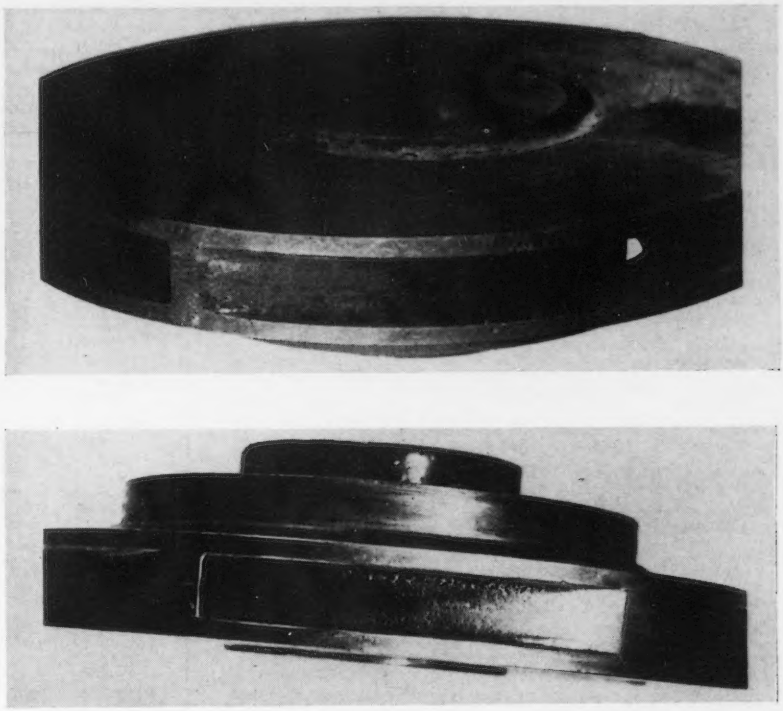


Figure 7—Top photograph shows a pearlitic ductile iron impeller after service for 5920 hours; bottom photograph shows a 13 percent chromium stainless steel impeller after service for 4801 hours in boiler feed pump.

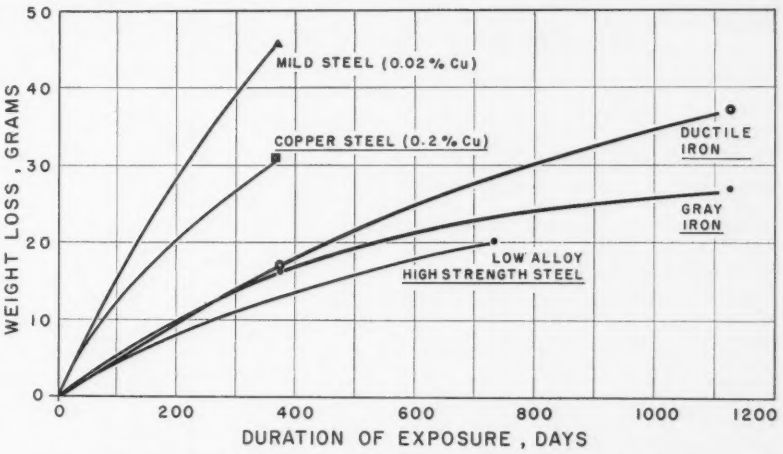



Figure 8—Results of exposure of steels and cast irons to corrosion by the atmosphere 80 feet from the ocean at Kure Beach, N. C. Specimen size was 4 x 6 inches.

Quantitative data from exposure of speciments for 3½ years, 80 feet from the ocean at Kure Beach, N.C., have been plotted as weight loss versus time curves in Figure 8. Data on a low copper mild steel, a typical copper steel and a low alloy high strength steel containing nickel, copper and chromium tested at the same site have been included for comparison.

It will be observed that the cast irons compare favorably with the alloy steel and are greatly superior to mild steel and copper steel in resisting attack by this very aggressive salt atmosphere.

**TABLE 3—Results of Burial of Irons in Beach Soils**

| Test Location | PENETRATION BY CORROSION IN IPY | |
|---|---|---|
| | Ductile Iron | Grey Cast Iron |
| Le Touquet..... | 0.047 | 0.069 |
| Mont St. Michel... | 0.045 | 0.043 |

This good resistance to sea spray is, no doubt, an important factor in the successful use of ductile iron as an improvement over steel in applications aboard tankers and other ocean-going vessels. The good resistance of cast irons including ductile iron to atmos-

**TABLE 4—Results of Tests of Ductile Iron in Several Media**

| Corrosive Medium | CONDITIONS OF EXPOSURE | Corrosion Rates, Inches Penetration/Year: Pearlitic | Ferritic |
|---|---|---|---|
| **Alkalies:** | | | |
| Ammonium Hydroxide | Vapor section of still at 185 F for 109 days. Vapor contained 40% $NH_3$, 9% $CO_2$, 51% $H_2O$ by volume. | 0.040 | 0.039 |
| Hafnium Hydroxide | Solution for 58 days containing $(NH_4)_2SO_4$ and $NH_4OH$ at pH 7.5—8.5 and at 113 F | 0.015 | .... |
| Sodium Hydroxide | 10% at 122 F for 30 days | 0.0005 | 0.0004 |
| Sodium Hydroxide | 30% containing heavy concentration of salt at 183 F for 82 days | 0.008 | 0.008 |
| Sodium Hydroxide | 50% containing heavy concentration of salt at 131 F for 173 days | 0.0012 | 0.0014 |
| Sodium Hydroxide | 50% saturated with salt at 203 F for 67 days | 0.012 | 0.012 |
| Sodium Hydroxide | 50% at 70—260 F for 19 days | 0.016 | ..... |
| Sodium Hydroxide | 74% at 260 F for 20 days | 0.16 | 0.16 |
| Sodium Hydroxide | Molten at 950 F for 14 days | 0.16 | ..... |
| **Acids, Mineral:** | | | |
| Sulfuric Acid | 79-93% containing phosphine, ammonia and hydrogen sulfide for 20 days at 65 F. Agitated but air free | 0.029 | .... |
| Sulfuric Acid | 83.4% at 90F<br>83.4% at 120 F | 0.031<br>0.086 | ....<br>.... |
| Sulfuric Acid | 93.4% at 90 F.<br>93.4% at 120 F | 0.012<br>0.018 | ....<br>.... |
| Sulfuric Acid | 99.6% at 220 F.<br>99.6% at 250 F | 0.011<br>0.005 | ....<br>.... |
| Sulfuric Acid | 96-99% containing ferric sulfate, ferric chloride and saturated with HCl for 163 days at 80 F | 0.006 | 0.007 |
| Sulfuric Acid | 100.5-101.5% for 32 days at 300-325 F | 0.021 | 0.013 |
| **Acids, Organic:** | | | |
| Cresylic Acid | Solution containing small amount of $H_2SO_4$ and miscellaneous organic sulfurous compounds for 60 days at 350 F | 0.044 | .... |
| Fatty Acids | Reaction of fatty acids and NaOH to produce 50% free fatty acids and 50% Na and Al soaps. 75 days at 370 F | 0.025 | .... |
| Fatty Acids | Twitchellized mixed fatty acids for 61 days at 77 F | 0.003 | .... |
| Fatty Acids | 95% acidulated mixed fatty acid soapstock for 60 days at 77 F | 0.002 | .... |
| **Salts, Acid:** | | | |
| Ammonium Sulfate | 10% at pH 4.8 for 5 days at room temperature. Aerated and agitated | 0.017 | 0.015 |
| Lithium Chloride | Concentration and temperature not reported. Duration of test 153 days | 0.008 | .... |
| Sodium Bicarbonate | 44% slurry containing $NH_4Cl$, $NH_4HCO_3$, NaCl, $CO_2$ and sulfides for 64 days at 86 F | 0.004 | 0.003 |
| Sodium Bicarbonate | 20% slurry containing $NH_4HCO_3$, $NH_3$, $CO_2$, $NH_4Cl$, NaCl and trace $Na_2S$ for 280 days at 86 F | 0.002 | .... |
| **Salts, Neutral and Alkaline:** | | | |
| Calcium Chloride | Aerated spray of 77% $CaCl_2$ containing sodium bichromate inhibitor at pH 7.0-8.5 for 338 days at 3-4 F | 0.002 | .... |
| Calcium Chloride | 77% $CaCl_2$ containing sodium bichromate inhibitor at pH 7.0-8.5 for 338 days at boiling temperature | 0.0002 | .... |
| **Salts, Neutral and Alkaline:** | | | |
| Sodium Chloride | 3.5% for 28 days at 86 F. Aerated | 0.029 | .... |
| Sodium Chloride | 14.5% containing calcium, magnesium and potassium salts plus free bromine and chlorine at pH 2-5 for 365 days at 187 F. No aeration | 0.032 | .... |
| Sodium Chloride | 15% solution containing 9% NaOH and 1% $Na_2SO_4$ for 32 days at 180 F. No aeration | 0.021 | 0.017 |
| Sodium Chloride | 25% NaCl bittern for 168 days at 169 F. No aeration | 0.028 | .... |
| Sodium Chloride | In 25% NaCl bittern containing magnesium and potassium salts at pH of 2-5 for 90 days at 169 F. No aeration | 0.046 | .... |
| Sodium Chloride | 25% NaCl bittern containing calcium salts and $NH_3$ to pH of 6.0-6.5 for 61 days at 50 F. Moderate aeration | 0.003 | 0.003 |
| Sodium Chloride | 25% NaCl solution containing $CaCl_2$ and $CaSO_4$ at pH 6.5 for 180 days at 50 F | 0.010 | .... |
| Sodium Chloride | Mixed solution of NaCl and $KNO_3$ for 90 days at 190 F | 0.006 | .... |
| Sodium Chloride | Ammoniated Brine Liquor for 107 days at 130 F | 0.003 | .... |
| **Coke By-Product:** | | | |
| Coal Tar Vapors | Distilled vapors for 306 days at 425 F | 0.090 | .... |
| Coal Tar Vapors | In reflux condenser for 306 days at 450 F | 0.03 | .... |
| Coal Tar | On top plate of fractionating tower for 154 days at 390 F | >0.189 | .... |
| Coal Tar | On middle plate of fractionating tower for 154 days at 515 F | 0.009 | .... |
| Coal Tar | On bottom plate of fractionating tower for 154 days at 500-600 F | 0.004 | .... |
| Coke Quenching | Ammonia still waste water in spray quenching of coke for 180 days at room temperature to over 212 F. Highly aerated. | 0.023 | .... |
| Coke Quenching | Quench water containing traces of $CaSO_4$, $CaCl_2$ and $NH_4Cl$ at pH 6.5 for 11 days | 0.15 | .... |
| Coke Quenching | Quench water containing traces of $CaSO_4$, $CaCl_2$ and $NH_4Cl$ at pH 6.5 for 11 days | 0.30 | .... |
| **Flue Gas and Condensate:** | | | |
| Flue Gas | Boiler fired flue gas containing $SO_2$, $SO_3$, $H_2O$ and some vanadates for 158 days at 330 F | <0.0001 | .... |
| Flue Gas Condensate | Flue gas condensate containing $SO_2$, $SO_3$, $H_2O$ and some vanadates for 158 days at 80-100 F | 0.06 | .... |
| **Molten Metals and Salts:** | | | |
| Phosphorus | Molten phosphorus for 185 days at at 140 F | 0.0007 | .... |
| Zinc Chloride | Galvanizing flux containing 80% $ZnCl_2$, 10% KCl and 10% NaCl for 46 days at 700 F | 0.74* | .... |
| **Organic Compounds:** | | | |
| Diethylene Glycol | 50% diethylene glycol, 38% ethylene glycol, 4.5% $H_2O$, 4% $Na_2SO_4$, 2.7% NaCl, 0.8% $Na_2CO_3$ at pH 8-9 for 85 days at 275-300 F | 0.006 | 0.006 |
| Monoethanolamine | 28% solution of monoethanolamine made up with steam condensate plus $CO_2$ and $H_2S$ for 245 days at 256 F | 0.018 | .... |

* Severely graphitized.
† Graphitized.
‡ Slight graphitization.

**TABLE 4—(Continued)**

| Corrosive Medium | CONDITIONS OF EXPOSURE | Corrosion Rates, Inches Penetration/Year | |
|---|---|---|---|
| | | Pearlitic | Ferritic |
| **Organic Compounds:** | | | |
| Beta Naphthol | Distillation of impure beta naphthol containing <1% hydroxynaphtholic acid and tarry polymers—slightly alkaline—for 21 days at 400 F | 0.63 | 0.30 |
| **Paper Industry Media:** | | | |
| Black Liquor | Black liquor solubles from semi-chemical pulping of aspen wood containing 9% $Na_2SO_3$, 3% $Na_2CO_3$ at pH 6.8-7.3 for 37 days at 160 F | 0.07 | .... |
| Kraft Stock | Pulp stock containing .015 gpl $H_2SO_4$, .045 gpl $SO_4$, .025 gpl sulfide at pH 6.9 for 529 days at 100 F | 0.007 | 0.007 |
| Kraft and Neutral Sulfite Stock | Pulp stock containing .049 gpl $H_2SO_4$, .068 gpl $SO_4$, .038 gpl sulfide at pH 6 for 655 days at 100 F | 0.006 | 0.005 |
| Kraft White Water | White water containing .045 gpl $SO_4$, .025 gpl sulfide, 102 ppm chlorides at pH 7.3-8.2 for 98 days at 45-85 F | 0.007 | .... |
| Kraft White Water | White water containing .045 gpl $SO_4$, .025 gpl sulfide, 102 ppm chlorides at pH 7.3-8.2 for 86 days at 45-85 F | 0.006 | .... |
| Mill Waste Water | Waste water from alkaline pulp bleaching for 148 days at atmospheric temperature | 0.039† | .... |
| **Paper Industry Media:** | | | |
| Mill Waste Water | Waste water containing some ammonia and sulfide for 107 days at 120-140 F | 0.013 | .... |
| **Waters:** | | | |
| Fresh Water | Water containing small particles of phosphorus and soda ash to a pH of 9 for 184 days at 140 F | 0.001 | .... |
| Fresh Water | Hot water 83% of time and in molten sulfur 17% of time. Total exposure 61 days at 330 F | 0.28 | .... |
| Fresh Water | Tap water at Bayonne, N.J. for 28 days at 86 F | 0.027 | .... |
| River Water | Savannah River water at pH of 6.3 containing 1300 ppm chlorides, 75 ppm $SO_4$ and 20 ppm sulfides for 148 days at atmospheric temperature | 0.012‡ | .... |
| Sea Water | Laboratory test in aerated sea water for 19 days at room temperature | 0.010 | 0.010 |
| Sea Water | Aerated sea water at pH 7.5 to 8.3 with 2 ppm residual chlorine for 250 days at atmospheric temperature | 0.012 | .... |
| Sea Water | At Harbor Island at atmospheric temperature for 3 years | 0.010 | .... |
| Spring Water | Sulfur spring water containing 124 ppm $CaCO_3$, 24 ppm $SO_4$, 12 ppm sulfides, 14 ppm chlorides, total solids 269 ppm at pH 9.4 for 120 days at 120 F | 0.001 | .... |

* Severely graphitized.
† Graphitized.
‡ Slight graphitization.

pheric corrosion, beyond that conferred by nickel, copper or other alloying elements plus phosphorus in the matrix, may be attributed to the contributions made by graphite to the protective value of the corrosion products that develops. This is shown by the curves in Figure 8. As the protective rusts form on the cast irons the rates of corrosion as indicated by the slopes of the weight loss versus time curves decrease to a considerable extent.

## Resistance to Underground Corrosion

There has been no hesitation in adopting ductile iron for use underground, owing to the long record of successful use of cast iron in such environments, especially in the form of pipe. Ductile iron is a relatively new material and in addition there is no reliable accelerated test to predict resistance of cast irons to corrosion by soils. Thus it has not been possible to acquire data covering a sufficient duration of experience to define precisely the actual merit of ductile iron in resisting attack by the many varieties of soils that may be encountered.

Some data have been secured from tests on specimens buried in a clay soil at a depth of three feet for three years at two beaches in Europe. The beaches were completely submerged at high tide so that the exposure must be considered as being abnormally corrosive as compared with most soil conditions. In these tests, ductile iron resisted attack to about the same extent as grey cast iron, as shown by the data in Table 3.

Ductile iron is being included in a new series of underground corrosion tests to be undertaken by The National Bureau of Standards. Data from this source will become available in due course. In the meantime, use of ductile iron underground need not be restrained by fears of inadequate resistance to corrosion as compared with other ferrous materials.

## Resistance to Corrosion in Applications on Tankers

Difficulties with corrosion of steel, especially in the form of filling and discharge piping on deck and for heating coils in tank compartments have been responsible for a very considerable use of ductile iron pipe and valves in this service.

The most acute corrosion of steel has been encountered in tankers handling crudes from the Middle East.[12, 13] This attack is characterized by being in the form of very large and deep pits which develop principally on upward facing horizontal surfaces, (e.g., the upper third of the circumference of a horizontal pipe or coil). The exact mechanism of the pitting is not known. It evidently involves some electrolytic action between the actively corroding surfaces at the bottoms of persistent pits. These areas are anodic to relatively large surfaces covered with films of insoluble corrosion product oxides adjacent to them (and also possibly to surfaces well removed). The corrosion reaction is stimulated by acidic corrosion products which remain in the pits and keep the surfaces active between the cyclic exposures to crude oil and salt water for ballast. The paraffins deposited from these crude oils appear to play some part in intensifying the electrochemical corrosion reaction through some effects on the cathodic films. The attack proceeds while the tanks contain salt water used for ballast.

The superior resistance of ductile iron to such tanker corrosion can be accounted for by such factors as:

1. Galvanic (cathodic) protection from the less noble steel tank walls and bottoms, etc.
2. Development in the early stages of corrosion of graphitic corrosion products which are as noble as the oxide films that form on iron and steel, thereby eliminating the galvanic potential believed to be the driving force responsible for the pitting of steel.

Thus, pits that can trap corrosion perpetuating acidic corrosion products do not get started in the ductile iron or, if started, heal fairly quickly by the formation of a protective layer of graphitic corrosion products.

Some of the early installations of ductile iron loading pipes in French tankers developed shallow pits early in their life. Although this pitting subsequently subsided without serious damage, its occurrence led to trials of ductile iron pipe containing 1.5 percent nickel.[6] This nickel alloyed ductile iron exhibited even better resistance to pitting and other forms of corrosion. The mechanism of the beneficial effect of nickel is not yet clear. It may have included some additional galvanic (cathodic) protection from the associated carbon steel which would be expected to be about 50 millivolts less noble than the alloyed ductile iron. With the favorable area relationship that exists in such a combination, this potential difference would be sufficient to give the alloyed ductile iron a substantial amount of cathodic protection.

Experience confirmed by comparative tests in tankers in Europe has shown that nickel alloyed ductile iron heating coils and loading pipes were superior to unalloyed ductile iron with respect

to resistance to pitting. This has led to a preference in Europe for the alloyed iron for this service. Elsewhere the unalloyed iron is being applied for the same purposes. The relative merits of the two types of ductile iron will become more clearly established by more experience.

### Miscellaneous Environments

Specimens of ductile iron have been included in many tests in miscellaneous corrosive media, especially in the chemical and process industries. A great number of these tests have been made with standard corrosion test spools in accordance with A.S.T.M. Recommended Practice for Conducting Plant Corrosion Tests.[14] Such data have been assembled in Table 4 for convenient reference.

### Conclusion

By and large, ductile iron can be considered as having satisfactory corrosion resisting properties which will permit its use as a substitute for grey iron, malleable iron or steel where these are regularly used. In some instances it will demonstrate a useful corrosion advantage over one or other of these materials to an extent that will become more precise as this promising youngster in the metal field comes of age.

### Acknowledgment

The author is grateful for the help provided by his associates in the Development and Research Division at The International Nickel Company, Inc. in carrying out the tests which yielded the data included in this paper and in preparing the photomicrographs used for illustration.

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**Any discussions of this article not published above will appear in the December, 1958 or June, 1959 issues**

# Corrosion Protection for Pipe Type Electric Transmission Lines in the Chicago Area*

By W. T. ROSE

**Abstract**

Pipe type high voltage transmission lines used in the Chicago area were protected with either an asphalt mastic coating or a reinforced coal tar enamel coating. Both are factory applied. Cathodic protection was then applied to these lines to police the pin holes in the coating. Before cathodic protection could be economically applied, it was necessary to insulate the pipes from the station ground busses. It was also necessary to maintain a low resistance path between the pipes and the ground busses for fault current in the event of a service failure. This was accomplished by using oxide film cut-out disc in the ground connections. Both magnesium anodes and a rectifier were used to provide cathodic protection. 7.2

FOR SOME YEARS the gas and petroleum industries have used buried pipes for long distance transmission of gas and various petroleum products. Cast iron and wrought iron pipe are used at low pressures, and steel at high pressures. These lines may be bare or may have any number of kinds of coatings, depending on the nature of the product handled.

It has been only recently that coated steel pipes have been used by electric utility companies in connection with high voltage transmission lines.[1] In the Chicago area the first pipe type transmission lines were installed in 1950. These were short lines and operated at 69 KV. Since that time all installations have been designed for 138 KV operation.

About the Author

**WELLON T. ROSE is engineer for the Commonwealth Edison Company, Chicago, Illinois. He holds a BS in electrical engineering from Clemson College, and is a registered professional engineer. He has been actively engaged in corrosion control since 1942 except for 30 months in the Navy. Mr. Rose is a member of NACE.**

### System Design

For electrical transmission it is necessary to maintain a continuous low resistance path for fault current in the event of a service failure. For that reason it is not practical to use insulating joints in the pipe of an electrical system. This introduces special problems in applying cathodic protection. Several rather unique methods have been devised to insulate the pipe from the station ground bus and yet provide a low resistance path for fault current.

Large manholes must be installed approximately 2000 feet apart, so that the copper conductors can be installed or replaced if necessary. Special joints are needed in these manholes to connect the conductors and to seal the pipe around the conductors.

Thermocouples are installed at various locations so that the pipe temperature may be kept at a safe level. The load capability of an electrical transmission line is determined by the conductor size and the allowable operating temperature. To obtain the most economical overall installation it often is necessary to bury the pipe a minimum of six feet deep.

It is necessary to have a very good coating on the pipe, so that when cathodic protection is applied, the pipe in question will not cause corrosion of other near-by buried metallic structures. This coating also is desirable to prevent costly repairs due to corrosion on the pipe itself.

### Construction Methods

In Chicago, pipe used for high voltage lines are either 5, 6, and 8 inches in diameter. Most of these pipes are protected with an asphalt mastic coating (i.e., a coating made up of asphalt, sand, crushed stone, and asbestos fibers.) The remaining pipes are protected with a high temperature coal tar enamel, which is reinforced with a glass fiber tape. One wrap of 15 pounds asbestos felt is applied over the enamel and the coating is protected with heavy kraft paper.

Both of the above coatings are factory applied. At the terminals, three copper pipes are used between the steel pipe and the potheads. These copper pipes are taped with industrial plastic tape. In each manhole the bare portion of the pipe and pipe joints are protected with grease and a wrapper. Much of the pipe must be snaked under obstructions into position in the trench, and during this operation the coating may be damaged. Before backfilling the coating is "jeeped" to locate "holidays" in the coating. On the asphalt mastic coated lines 26,000 volts is used in this connection and on the coal tar enamel 15,000 volts is used. These are peak voltages.

Pipes normally are installed in natural earth, usually clay, on a layer of sand. Sand is placed around the pipe to a depth of about 6 inches before backfilling. In some areas, local ordinances require that only sand be used for backfilling.

### Testing

After the pipe has been backfilled and soaked with water, a resistance measurement of the coating is made. A minimum of 17 megohms per square foot of the coating is required for acceptance. If the resistance is low or other observations indicate that the coating may be damaged, then an overground survey is made to locate the "holiday" (see Figure 1.)

In the survey a reversing DC potential of approximately 400 volts is placed on the pipe. This potential is reversed approximately every ten seconds. Voltage readings are then taken between a copper $CuSO_4$ half cell placed over the pipe line and a remote steel ground rod.

The half cell is moved along the pipe and readings taken at about five foot intervals. These intervals are shortened to accurately pin point a "holiday." The "holiday" can be located by marking the

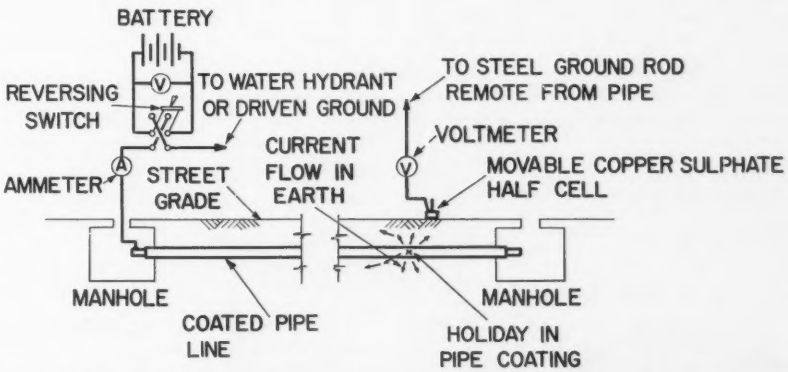



Figure 1—Method used for making overground survey on buried pipes, coated with asphalt mastic or reinforced coal tar enamel.

★ Submitted for publication November 1, 1957. A paper presented at a meeting of the North Central Region, National Association of Corrosion Engineers, Chicago, Illinois, October 1-4, 1957.

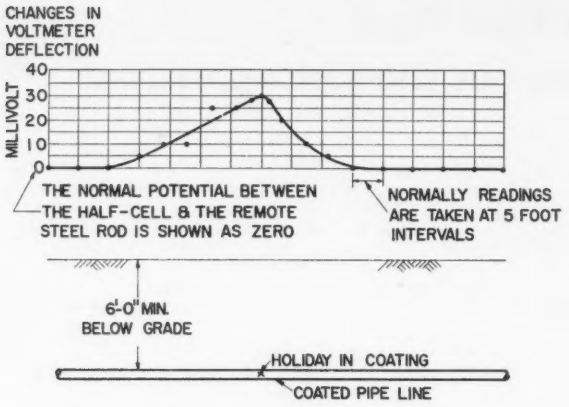



Figure 2—Locating holiday in pipe coating by overground survey.

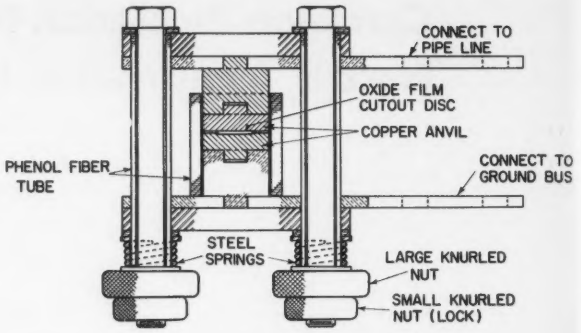



Figure 3—Voltage break-down gap.

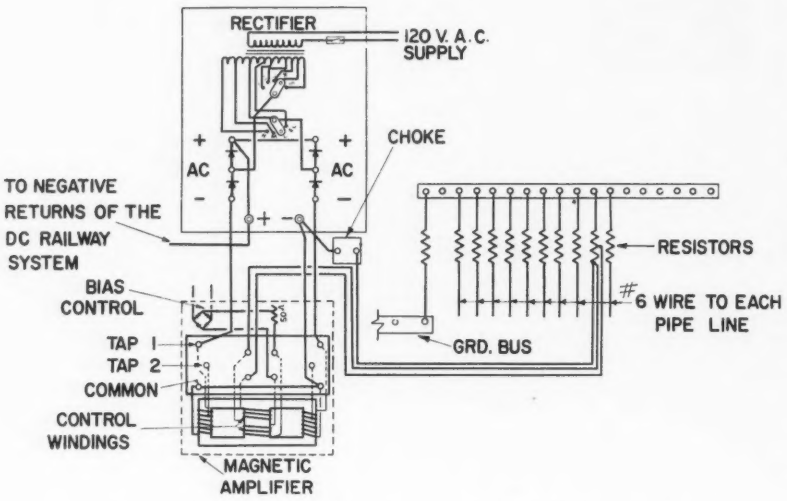



Figure 4—Method of connecting the cathodic protection rectifier to the various pipe lines.

position of the half cell when the voltmeter shows the greatest change in deflection. These changes in deflection will occur when the DC potential on the pipe is reversed as shown in Figure 2. Normally, by using this method, the "holiday" can be located accurately. However, in stray DC areas, and when two or more "holidays" are close together, pin pointing can be very difficult. A voltmeter, which has a resistance of 200,000 ohms per volt, is used for such work.

With the pipe installed at six to eight feet below the surface, an applied voltage of about 400 volts was found to be ideal to pin point "holidays" in a coating that failed to pass the resistance requirement. The voltage is reduced when surveys are made on pipes that are less than six feet deep.

## Cathodic Protection

Cathodic protection is used to "police" the small pin holes in the coating, that cannot be located with test methods now available. This is accomplished by insulating the pipe at both ends from station ground busses and connecting the pipe to 17 lb. magnesium anodes which are buried below the floor of each manhole.

To provide the required electrical connection between the pipe and the station ground bus, for fault currents, oxide film cutout discs are used. Figure 3 shows the complete assembly of this voltage break down gap. In case of a fault, the disc breaks down and solidly connects the pipe to the station ground bus. These discs are backed with copper anvils to increase the current carrying capacity.

Some difficulty was originally encountered on some of the lines with these cutouts. They had a tendency to break down from switching surges, and required frequent replacing. To reduce this form of trouble a one ohm resistor was placed in parallel with the troublesome film cutouts.

On the longer lines the magnesium anodes did not provide complete corrosion protection. The large voltage gradients in the earth, caused by uninsulated negative returns of the DC railway systems, overcame the driving potential of the magnesium anodes so that they would pick up stray current in some areas and discharged this current in other areas. To overcome this condition, a rectifier was installed near the center of the pipe line system and connected between the pipes and the negative returns of the DC railway system through a magnetic amplifier. This arrangement is shown in Figure 4.

The rectifier primarily serves as a means of returning the stray railway current to the negative return system, which in this case is the street car rails. In addition, the rectifier maintains a satisfactory voltage drop across the one ohm resistors, connected in parallel with the film cutouts at the station ground busses. The magnetic amplifier regulates the output of the rectifier and compensates for the high voltage changes of the negative return system. Resistors, used in series with each pipe, control the amount of current from the various pipes. An output of 15 amperes provides corrosion protection for approximately 30 miles of pipe.

The rectifier has sufficient capacity to provide protection for future installations. It and the resistors are adjusted to maintain a minimum negative potential of 0.85 volts between the pipes and a remote copper $CuSO_4$ half cell.

## Conclusion:

Corrosion protection was provided for pipe type transmission lines by the following steps:

1. Separating the pipes from the various station ground busses, so that cathodic protection would be effective.

2. Making certain that the pipe had a very good coating.

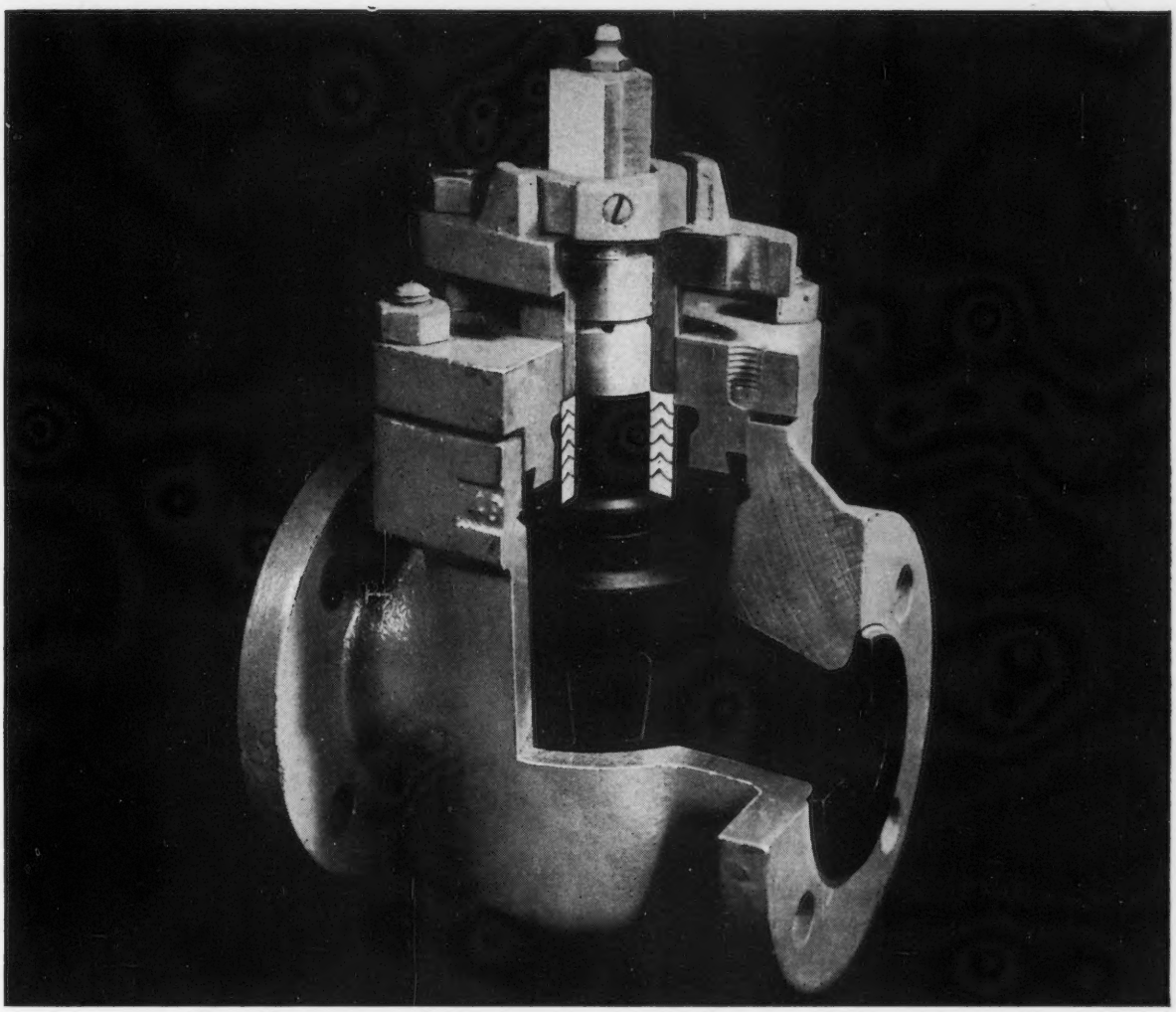
3. Applying cathodic protection to the pipe by burying magnesium anodes at approximately 2,000 foot intervals.

4. Providing a rectifier to take care of stray currents that the anodes could not handle.

5. Installing a magnetic amplifier with the rectifier to control output and thus prevent damage to the coating.

## Reference

1. Pipe Type Cable Corrosion Protection Practices in the Utility Industry (Report of Technical Unit Committee T-4B- on Corrosion of Cable Sheaths.) *Corrosion*, **10**, No. 9, 299-313 (1954) September.



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**Turn to Page 69 of September CORROSION for a schedule of the technical committee meetings to be held at New Orleans during the October 20-24 South Central Region Conference and Exhibition.**

**TECHNICAL REPORTS**

**on**

**PIPE LINE CORROSION**

**T-2** Statement on Minimum Requirements for Protection of Buried Pipe Lines. Prepared by a Special Task Group of NACE Technical Group Committee T-2 on Pipe Line Corrosion. Publication No. 56-15. Per Copy $.50.

**TP-2** First Interim Report on Galvanic Anode Tests. (Pub. 50-2) NACE members, $3; Non-members, $5 Per Copy.

**TP-3** First Interim Report on Ground Anode Tests. (Pub. 50-1) NACE members, $3; Non-members, $5 per copy.

**T-2B** Final Report on Four Annual Anode Inspections. A Report of Technical Unit Committee T-2B on Anodes for Impressed Current. Publication 56-1. Per Copy $1.00.

**T-2B** Use of High Silicon Cast Iron for Anodes. First Interim Report of Unit Committee T-2B on Anodes for Impressed Current. Publication No. 57-4. Per Copy $.50.

**T-2C** Some Observations of Cathodic Protection Potential Criteria in Localized Pitting. A Report of T-2C on Minimum Current Requirements for Cathodic Protection. Pub. 54-2. Per Copy $.50.

**T-2C** Some Observations on Cathodic Protection Criteria. A contribution to the work of NACE Technical Unit committee T-2C. Publication No. 57-15. Per Copy $.50.

**T-2D** Methods for Measuring Leakage Conductance of Coating on Buried or Submerged Pipe Lines—A Report of Tech. Unit Committee T-2D on Standardization of Procedures for Measuring Pipe Coating Leakage Conductance. Pub. 57-27, Per Copy $.50.

**T-2G** Tentative Recommended Specifications and Practices for Coal Tar Coatings for Underground Use. A Report of Technical Unit Committee T-2G on Coal Tar Coatings for Underground Use. Per Copy $.50.

**T-2H** First Interim Report. Tentative Recommended Specifications for Asphalt Type Protective Coatings for Underground Pipe Lines—Wrapped Systems. A Report of NACE Technical Unit Committee T-2H on Asphalt-type Pipe Coatings. Publication No. 57-11. Per Copy $.50.

**T-2H** Second Interim Report. Tentative Recommended Specifications for Asphalt-type Protective Coatings for Underground Pipe Lines—Mastic Systems. A Report of NACE Technical Unit Committee T-2H on Asphalt-type Pipe Coatings. Publication No. 57-14. Per Copy $.50.

Remittances must accompany all orders for literature the aggregate cost of which is less than $5. Orders of value greater than $5 will be invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 65c per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

**NATIONAL ASSOCIATION OF CORROSION ENGINEERS**

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# *Oil and Gas Well Equipment Corrosion Manual to Be Sold at New Orleans*

A new manual, Corrosion of Oil- and Gas-Well Equipment, written to help field operating personnel understand corrosion problems, was scheduled to be published in September. The manual was written and compiled by a special editorial subcommittee of NACE Technical Group Committee T-1 and reviewed by a special subcommittee of the American Petroleum Institute.

Corrosion Engineers combined their knowledge to write the manual in order to bridge the gaps in understanding between technologists and operating personnel. It is intended for use by foremen, pumpers, well tenders and others, to induce them to play a valuable part in cutting corrosion costs. Its stated purpose is to:

1. Present to operating personnel the tremendous cost of corrosion.
2. Enable them to recognize early indications of corrosion.
3. Emphasize the importance of early reporting.
4. Encourage field personnel to take an active part in the solution of corrosion problems.

### Simple Terms Used

Because the manual is written for field operating personnel, it uses simple terms and descriptions. Basic proved methods used to control corrosion are explained in general terms only and no specific standards or recommendations are stated. It is not intended for use as an advanced work for corrosion scientists, nor as a guide to be used in specific cases.

The importance of field corrosion personnel to the successful control of corrosion is given in Chapter One of the manual. Also explained are the general types of corrosion and their economic aspects. Some case histories are given to prove that large amounts of money are saved by adequate corrosion control measures.

Sweet corrosion problems are dealt with in Chapter Two. The chemistry of corrosion in sweet oil and gas wells is given, as is also a description of the different types of corrosion damage to various apparatus and well installations. Gas-condensate and oil wells both are considered. Methods for evaluating the extent of corrosion are described and general kinds of preventive measures and procedures are given.

### Sour Oil Corrosion Covered

Sour oil corrosion is dealt with in Chapter Three of the manual. Average cost of corrosion on wells without any kind of protection is given as about $150 per well per month for equipment failure. Replacement costs on equipment on all such wells could be well over 32,000,000 yearly, it was estimated.

The chemical formula describing the general corrosion reaction in sour corrosion is given and explained. Oxygen and carbon dioxide, while not necessary to cause corrosion, greatly speeds up corrosive reactions when they are present, it is stated.

A description of damage in oil-well tubing corrosion is given, and annular-space corrosion is described. Corrosion of equipment for water or gas injection can be expected to show generally the same corrosion as comparable production equipment, it is pointed out.

Various methods for evaluating the extent of the corrosion problem are given. Drawbacks to the use of calipers are related. Test coupons are used to indicate whether corrosion is occurring, and used properly and under certain conditions give very accurate results, it is asserted.

Records of equipment failure are said to be the best method to determine the extent and severity of corrosion. Equipment failure records are extremely important in determining the extent of corrosion and efficiency of a corrosion-control program. Value of records is stressed in the manual.

### Control Methods Discussed

The discussion of control methods covers design and operating techniques, an explanation of the use of inhibitors as an economical control method and use of non-metallic materials.

Under the heading, Economics of Corrosion Control, the manual explains that because of the complexity of the problem, it sometimes is more economical to establish good general methods for treating all wells in a system, rather than vary procedures to fit precise requirements of individual wells.

Appendices to the manual contain a glossary of terms, a bibliography, more detailed information on oil-well pumps and an extensive explanation of survey methods used in cathodic-protection studies.

### To Be Sold at New Orleans

Orders for the publication will be taken at the NACE South Central Region Conference, New Orleans, October 20-24, according to J. D. Sudbury, Continental Oil Co., chairman of the NACE editorial subcommittee which compiled the manual. Price will be $2.50. Work on the book has been underway for some years. It was initiated while W. F. Oxford, Jr., Sun Oil Co. was chairman of Technical Group Committee T-1 on Corrosion in Oil and Gas Well Equipment. Jack L. Battle, Humble Oil and Refining Co. is T-1 chairman now.

In addition to chairman Sudbury, the editorial subcommittee members were: J. P. Barrett, Pan American Petroleum Corp.; H. E. Greenwell, the Atlantic Refining Co.; F. A. Prange, Phillips Petroleum Co. and E. W. Wallace, Shell Oil Co.

The API review committee was composed of J. R. Hatfield, Cities Service Oil Co., chairman; and members, T. S. Bacon, Lone Star Gas Co.; E. T. Heck, Minard Run Oil Co.; C. E. Hedborg, Union Oil Co. of Cal.; W. C. Koger, Cities Service Oil Co. and E. L. Petree, Gulf Oil Corp.

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# NACE NEWS

# Western Region Conference Opens November 17

## WESTERN REGION CHAIRMEN AND AUTHORS

Dorsey

Hill

Mason

Munger

Puckett

Richardson

Schillmoller

Scott

Seymour

Tandy

## BIOGRAPHIES

**J. W. CALDWELL**—Formerly an assistant mine superintendent working with acid waters at a titanium mine in Florida, he is presently concerned with applications of zinc in cathodic protection from a production and quality standpoint. He is affiliated with the Bunker Hill Co., San Francisco. Part of his past work has been in research, plant engineering and production supervision. He is a graduate of Colorado School of Mines as an engineer of mines. He is a member of NACE.

**E. F. EHMKE**—Corrosion engineer for the Tide Water Associated Oil Co., he has had extensive refinery engineering experience. He has studied corrosion and metallurgy specification for aluminum chloride-hydrochloric, sulfuric acid, naphthenic acid, hydrogen sulfide and other problems in refinery plants. He has a BS in chemical engineering; he is a member of NACE.

**W. J. FRITH**—Affiliated wth Paul Manuel Painting Contractor, Los Angeles, Mr. Frith has had almost 10 years' experience in indus-

(Continued on Page 70)

## *Notices Mailed on 1959 NACE Dues*

Notices for 1959 active and junior membership dues for the National Association of Corrosion Engineers were mailed in October, some two and one-half months earlier than they have been mailed in recent years. T. J. Hull, executive secretary, said this action was taken in the belief that many members would appreciate being reminded of their dues obligation before the winter holidays. Dues are payable by the year in advance before January 1, according to the NACE constitution and by-laws.

## Shreveport Hears Rench Talk on Plastic Coatings

Plastic Coatings and Their Applications and Corrosion Control was the subject of a technical talk by Joseph Rench scheduled for the September 2 meeting of the Shreveport Section. Mr. Rench is vice-president of Napko Corp., Houston. A social hour and dinner was slated to precede the meeting.

## Smith Added to Staff

Gordon B. Smith, Testing Metallurgist for Ampco Metal, Inc., Milwaukee is now CORROSION correspondent in non-ferrous metals.

## *In-the-Field Short Course to Be Held November 20-21*

The technical program is practically complete for the Western Region Conference and Corrosion Short Course to be held November 17-21. Only a few changes and additions will be made. The conference will be held November 17-19, at the Statler Hotel, Los Angeles. An in-the-field short course will follow on November 20-21.

The conference will open Monday morning with a welcoming address by E. F. Bladholm, Southern California Edison Co., general conference chairman. Following this a keynote address will be delivered by NACE President L. L. Whiteneck, Plicoflex, Inc.

Following is the tentative program:

**November 17, Afternoon**

**General Corrosion Round Table Discussion.** C. G. Munger, Amercoat Corp., chairman. Panel members and their fields:

Aluminum and magnesium alloys, T. J. Summerson, Kaiser Aluminum & Chemical Corp.

Special alloys for corrosion prevention in the oil industry, A. P. Maradudin, Standard Oil Co. of Cal.

Cathodic protection, G. N. Scott, consultant.

Metallic coatings, D. H. Gelfer, Amercoat Corp.

Concrete, D. Hausman.

Coal tar, R. C. Stromquist, Koppers Co.

Corrosion resistant plastics, R. B. Seymour, Loven Chemical Co.

**November 18, Morning**

**Refinery Symposium.** G. C. Hall, Richfield Oil Co., chairman.

Design of Butane Isomerization Units for Minimum Corrosion by J. F. Mason, Jr. and C. M. Schillmoller, International Nickel Co., Inc.

FSCC Gas Plant Hydrogen Attack by E. F. Ehmke, Tide Water Associated Oil Co.

Aluminum Solves Many Refinery Corrosion Problems by a speaker from Aluminum Company of America.

Radioactive Isotopes in Non-Destructive Testing, by E. H. Tandy, Standard Oil Co.

**November 18, Morning**

**Corrosion in Aircraft and Missiles Symposium.** H. H. Muller, Chemical Mill Div., Turco Products Co., chairman.

Use of Plating Techniques to Control Aircraft and Missile Corrosion by W. R. Castelle.

Role of Paint and Conversion Coatings in Aircraft and Missiles by C. Sheperd.

Missile Corrosion Problems by R. A. Geiger.

**November 18, Afternoon**

**Corrosion in Food Processing Sympo-**

(Continued on Page 70)

# WESTERN REGION AUTHORS BIOGRAPHIES

(Continued From Page 69)

trial painting contracting. He attended the University of Iowa and has been a student in numerous night and special courses. He is a member of NACE.

**D. H. GELFER**—Is a research chemist and has done work on electroplating processes and organic protective coatings. He holds BS and MS degrees in chemistry. He is affiliated with Amercoat Corp.

**G. C. HALL**—At the time he joined NACE in 1956, Mr. Hall was in charge of the corrosion control program in the Richfield Oil Corp. refinery. Everything but water-treating and cathodic protection of tanks and pipe lines were in his charge.

**R. W. HAWKSLEY**—Of Ray W. Hawksley Co. Inc., Richmond, Cal., has as his corrosion specialty industrial water treatment. He is a graduate of Massachusetts Institute of Technology with a chemical engineering degree. He is a member of National Association of Corrosion Engineers.

**P. W. HILL**—An engineer with Signal Oil and Gas Co., Los Angeles, he has been active in engineering and research projects in the California petroleum industry. A long time member of the Southern California Meter Association and the California Natural Gasoline Association, he has been active also in technical committee work for the National Association of Corrosion Engineers.

**C. E. LEE**—Is with Southern California Gas Co., Los Angeles. He has been a member of NACE since 1950. He has had extensive corrosion experience with pipe lines and protective coatings, water conditioning and refinery equipment. He is a mechanical engineer and has done research work.

**ALEXEI P. MARADUDIN**—Is affiliated with Standard Oil Company of California. He has been a member of NACE for more than nine years. He graduated from Stanford University as a metallurgical engineer.

**J. F. MASON, JR.**—In charge of development activities in the Petroleum Industry for the development and research division of the International Nickel Co., Inc. He has been a member of NACE since 1947. He joined the development and research division of International Nickel in 1937, in the corrosion engineering section. He is author of numerous articles and papers dealing with corrosion of metals and alloys in such process industries as petroleum, food-processing and chemicals. In addition to being a member of NACE, he is also a member of API, ASME and the Electrochemical Society. Before Joining International Nickel he was an instructor in chemistry at LaSalle Academy, New York City.

**C. G. MUNGER**—Vice-President in charge of manufacturing and research for Amercoat Corp. He has been active in NACE for many years both as an officer and on technical committees. Since 1936 his principal work has been in connection with corrosion research, particularly on steel and on concrete exposed to sewage conditions. He has worked on numerous problems for the armed services, the Atomic Energy Commission and private industry especially in connection with application of coatings and plastics.

He frequently speaks before technical organizations and has written numerous papers in his field. He has a BA in chemistry, Claremont College and did work in graduate chemistry there. Besides NACE he belongs to numerous other technical organizations.

**W. J. PRATHER**—With the Pacific Gas and Electric Co., San Francisco, he is a protective coatings engineer. He also has had extensive experience as chief chemist in an engineering laboratory. He is a member of National Association of Corrosion Engineers and has an AB in engineering chemistry from Stanford University.

**G. J. PUCKETT**—With the Western division of the Dow Chemical Co., he has been with the firm almost 20 years. In 1950 he was made corrosion engineer with Dow. He is a member of National Association of Corrosion Engineers; he has a BS from the University of California.

**J. P. RASOR**—A member of NACE since 1950, Mr. Rasor specializes in the design and construction of electrical holiday detectors. He is affiliated with Tinker & Rasor, San Gabriel, Cal. He holds a BS in mine engineering, EM from Missouri School of Mines. He is a member of AIME.

**C. M. SCHILLMOLLER**—Joined the staff of the west coast technical field section of the International Nickel Company's development and research division in 1956. Prior to that he was corrosion engineer for the Richfield Oil Corp. for two years. His early education was in Holland and the Netherlands East Indies. He completed his education at Australia's University of Sydney in 1952 with a bachelor of engineering degree in chemical engineering. He was a pilot in the Netherlands Air Force from 1941 to 1947. He is a member of NACE and API.

**GORDON N. SCOTT**—Author or co-author of 23 articles on corrosion, Mr. Scott is widely known among corrosion scientists. He received the NACE Speller Award in 1955, is listed in American Men of Science, 1944, 1949 and Chemical Who's Who, 1951. He holds patents on corrosion preventive processes and equipment. He holds an AB in chemistry, a BS in chemical engineering and a PhD in physical chemistry from the University of California. He is a consultant on corrosion.

**R. B. SEYMOUR**—Has been quite active in NACE affairs and is widely known for his work in the development of plastics. He is author of many technical articles on the subject and holds several patents. He was a contributing author to "Plastics in Building" and the Engineering Materials and Corrosion Handbooks; he also co-authored "Plastics for Corrosion Resistant Applications," with R. H. Steiner. He is president of Loven Chemical Co., Newhall, Cal.

**R. C. STROMQUIST**—Has been a member of NACE since Jan., 1944 when he was affiliated with Wailes Dove-Hermiston Corp. When the firm became a division of Koppers Co., Mr. Stromquist was made production manager of Koppers' Tar Products division. His corrosion specialty is the development of bituminous protective coatings, particularly for metal used underground, underwater and in corrosive atmospheres.

**T. J. SUMMERSON**—Is affiliated with Kaiser Aluminum and Chemical Corp. He has done research on stress corrosion of aluminum alloys and on the development and evaluation of accelerated laboratory tests for aluminized steel. He has been a member of NACE since 1952. He has a BS in chemistry and an MS in physical chemistry.

**E. H. TANDY**—Director of Western Region, NACE, Mr. Tandy has been a member since 1948. He was employed by Standard Oil Company of California in 1930 and since 1948 has been closely associated with corrosion and inspection problems. He was appointed head equipment inspector for the El Segundo refinery in 1948. For a time, in 1955, he was loaned by Standard to Petrobras at their 60,000-barrel refinery near Santos, Brazil to organize a corrosion and inspection section.

## Western Region—

(Continued From Page 69)

**sium.** J. Boyce, Food Machinery & Chemical Corp., chairman.

Corrosion as It Affects Design in Food Processing Equipment by speaker from Food Machinery & Chemical Corp.

Corrosion in Citrus Processing by H. A. Schual.

### November 18, Afternoon

**Marine Symposium.** N. H. Kelly, Richfield Oil Corp., chairman.

Experiments with Zinc Anodes on Steel Piling by J. Caldwell, Bunker Hill Co.

Additional subjects and speakers to be announced later.

Technical Committee T-8B, Los Angeles Area Refining Industry Corrosion.

Fellowship Hour, 6:30 pm.

Western Region Conference Banquet. Ladies invited. 8:00 pm.

### November 19, Morning

**Petroleum Producing Symposium.** P. W. Hill, Signal Oil & Gas Co., chairman.

Problems in Water Flooding by C. Jones.

Additional subjects and speakers to be announced later.

### November 19, Morning

**Utilities Symposium.** R. O. Dean, Pacific Gas & Electric Co., chairman.

Planned Painting Protects Power Plants by W. J. Prather, Pacific Gas & Electric Co.

Modern Practice for Prevention of Scale and Corrosion in Cooling Water by R. W. Hawksley, Ray W. Hawksley Co., Inc.

General Corrosion Problems of an Electric Utility by L. Baskette.

### November 19, Afternoon

**Chemical Process Industries Symposium.** G. J. Puckett, Dow Chemical Co., chairman.

Plastisols and Organosols—Metal Coatings Supreme by L. D. Maines.

The Corrosion of Stainless Steel in Phosphoric Acid by A. R. Morgan.

Stress Corrosion of Stainless Steels, a motion picture, courtesy M. G. Fontana, professor, metallurgical engineering and research, Ohio State University.

### November 19, Afternoon

**Underground Structures Symposium.** C. E. Lee, Southern California Gas Co., chairman.

General Problems in Protection of Underground Pipe by G. Asher.

New Materials for Underground Coatings by E. O. Partridge.

Problems of Water and Sewage in a Utility Co. by G. Paul.

Protection and Coatings on Four Corners Pipe Line by J. K. Alfred.

### Short Course Schedule

The in-the-field corrosion short course will be held at the Standard Oil Co. Rod & Gun Club. Chairman is J. Brown, Union Oil Co., vice chairman is D. Lark, Standard Oil Co. tentative program for the short course follows:

Cathodic Protection Instruments for Use and Control, J. Rasor, Tinker & Rasor Co., chairman. November 20, morning.

Surface Preparation for Protective Coatings—Methods of Surface Preparation, P. C. Briley, National Lead Co., chairman. November 20, afternoon.

Pipeline Coatings—Application of a Pipeline Coating or Lining, R. L. Hansen, Pipe Lining Co., chairman. November 21, morning.

Paint and Plastic Coatings—Application of Paint and Plastic Coatings, W. J. Frith, Paul Manuel Protective Coatings, chairman.

Registration fee for the conference is $12. This includes the banquet and fellowship hour. Registration fee for the short course is $5. Registration chairman is F. V. Wilby, Southern California Gas Co., P. O. Box 3249, Terminal Annex, Los Angeles 54, Cal. Registration may be made in advance, or at the conference Monday and Tuesday mornings.

## Ballots for NACE Officers Must Be in by October 12

Ballots for national officers and directors of the National Association of Corrosion Engineers must be received at Central Office, Houston before October 24. Tellers then will tabulate the votes.

NACE members were mailed ballots late in August. More than 2000 have been returned to Central Office and there is some possibility that a record vote will be cast.

***Corrosion control unlimited!*** No other supplier offers as many materials or as much practical experience in corrosion control. Federated's Corrosion Advisory Service can recommend the best for you from among magnesium and zinc; GALVANIC ANODES, for cathodic protection; LEAD SHEET, PIPE and FITTINGS; ZINC and ZINC ALLOYS; COPPER and ALLOYS; and PLATING MATERIALS, including copper, lead, cadmium, zinc and silver anodes; nickel salts and addition agents for plating baths. One of Federated's 22 sales offices is near you. Don't hesitate to call for advice. Federated Metals Division, 120 Broadway, New York 5. In Canada: Federated Metals Canada, Ltd., Toronto and Montreal.

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# Corrosion Course Scheduled at Key Biscayne

A five-day Third Annual Corrosion Control Short Course will be given by Miami Section November 10-14 at Key Biscayne Hotel, Miami. J. B. Prime, Jr., Florida Power & Light Co., Miami, director outlined a tentative program as follows:

**Monday, November 10**

Corrosion of Naval Aircraft, S. Goldberg, Bureau of Aeronautics, Washington, D. C.

**Tuesday, November 11**

Soil Box Demonstration, M. C. Miller, Allendale, N. J.

Microbiological Corrosion, Raymond F. Hadley, Sun Pipe Line Co., Philadelphia.

**Wednesday, November 12**

Corrosion Testing, T. P. May, The International Nickel Co., Inc., Wrightsville Beach, N. C.

Natural Gas Pipelines, Joe E. Frink, Florida Power & Light Co., Miami.

Lead Cable, D. T. Rosselle, Southern Bell Telephone & Telegraph Co., Atlanta.

**Thursday, November 13**

Cathodic Protection, W. J. Schwerdtfeger, National Bureau of Standards, Washington.

Polyvinylchloride Plastisols, J. Watson Pedlow, Quelcor, Inc., Chester, Pa.

Polyvinylchloride Pipe, A. H. Henning.

Neoprene and Hypalon, George K. Vogelsang, Gates Eng. Co., Wilmington, Del.

Transient Phenomena in Glasses, J. H. Healy, Milwaukee.

**Friday, November 14**

Marine Applications, Raymond P. Devoluy, Glidden Co., New York, N. Y.

Pipe Coatings, Christopher Georges, Pipe Line Service Corp., Atlanta.

Epoxy Coatings, H. W. Howard.

Coating Developments, Alexander S. Sternberg, Steelcote Mfg. Co., St. Louis.

Coating Comparison, F. C. Weber.

Cathodic protection supplies in new Cleveland warehouse.

## ANNOUNCEMENT! CSI OPENS CLEVELAND, OHIO PLANT

Here's another reason why you'll find it pays to check with CSI for help in preventing corrosion on buried metal structures of all kinds. Now, to serve you faster and better, CSI has opened a new office and warehouse at 1309 Washington Ave., Cleveland 13, Ohio.

CSI engineers are pioneers and experts in the cathodic protection of transmission and distribution pipelines, oil and gas well casing, tank bottoms, etc. They offer a complete line of:

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  - Dow magnesium anodes, including the new Galvomag
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**Box 7343, Dept. C-10**
**Tel. Circle 5-1351**


## *Teche Short Course Committee Named*

Committee members have been named for the June Teche Section Third Annual Short Course, according to John H. Selleck, Nocor Chemical Co., short course director. Various committees and members are:

Planning and Program committee, Mr. Selleck, chairman; Paul Bercegeay, Southwestern Louisiana Institute; and Vernon Sibille, The Superior Oil Co.

Speakers' committee, John D. Stone, Sunray Mid-Continent Oil Co., chairman; members, Lee R. DeRouen, Union Oil and Gas Corp. of Louisiana and Jim Alexander, Richardson and Bass.

Registration committee, Max I. Suchanek, Dowell, Inc., chairman; members, Frank Shofner, Aquaness Dept., Atlas Powder Co.; Sam Hopson, Tretolite Co. and Harry Owens, Amerada Petroleum Corp.

Housing and meals, W. A. Odom, Shearon Co., chairman; Phil Brock, Dowell, Inc. and Russell Pounds, Visco Products Co., members.

Entertainment, R. J. Cernik, Union Oil Company of California, chairman; member, Al Prats, Tube-Kote, Inc.

Publicity, Jack Donnelley, Plastic Applicators, Inc., chairman.

Formation of the committees was announced at the August 28 meeting of the section. Technical speaker for the meeting was L. V. Musgrove, Tex-Steam Corp., Houston, whose subject was Chemical Pumps in Corrosion Control.

## Oklahoma Corrosion Control Course Set March 31-April 2

The 1959 Corrosion Control Short Course of the University of Oklahoma will be held in cooperation with Central Oklahoma Section, National Association of Corrosion Engineers March 31-April 12, 1959. Classes will be at the Extension Study Center, North Campus, Norman.

The course, designed for field and technical personnel in refinery, oilfield and pipeline operations will have instructors experienced in the several fields presented. The $15 fee includes all instructional materials, copy of the proceedings and a certificate.

Additional information on any of the courses can be obtained from M. L. Powers, Director; Business and Industrial Services, Extension Division, University of Oklahoma, Norman.

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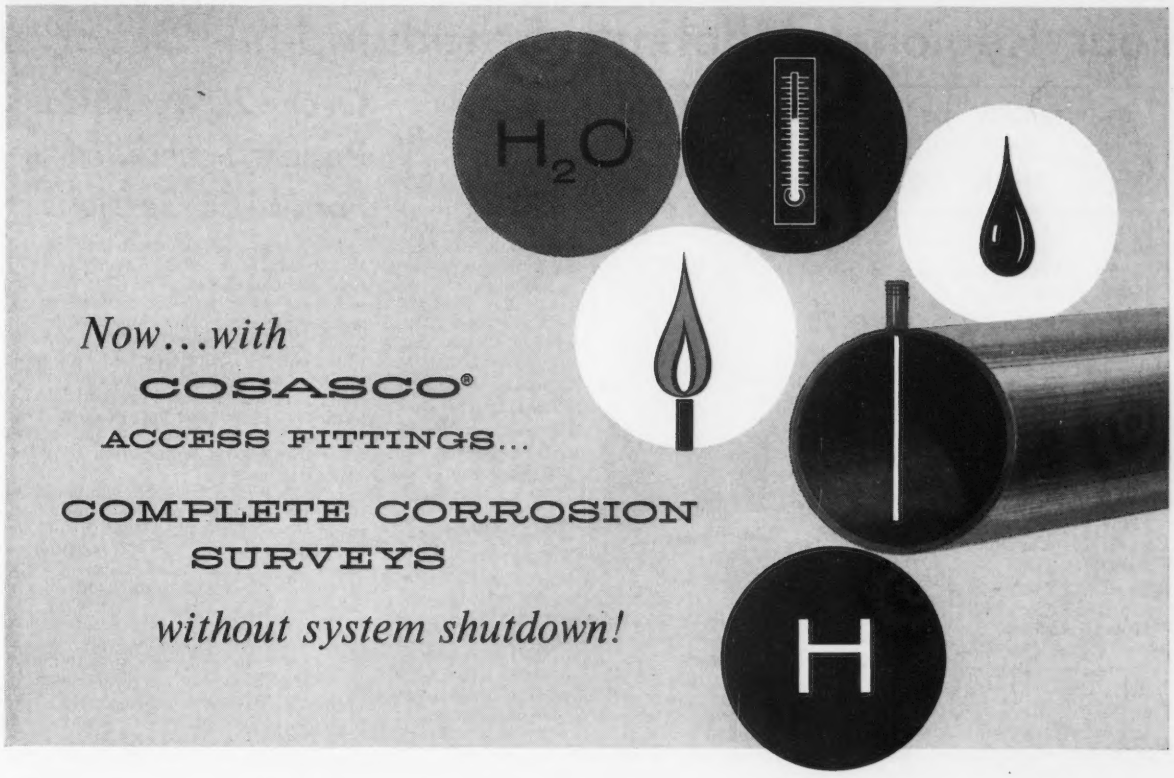
More than 20,000 cards have been issued by the NACE Abstract Punch Card Service.

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**COMPLETE CORROSION SURVEYS**

*without system shutdown!*

THE COSASCO ACCESS FITTING provides the key to successful corrosion survey work in transmission, storage, recovery and processing equipment. Previously, it had been difficult and costly—if not impossible—to run corrosion surveys inside pipelines and other pressure vessels without shutting down the system. Now, with Cosasco Access Fittings, corrosion surveys of all kinds can be made *under full operating pressures.*

**CORROSION COUPON SURVEY.** Enables the Corrosion Engineer to determine if corrosion is taking place. Grade 303 stainless steel coupon holder is installed through regular Cosasco Access Fitting body... can be easily inserted or withdrawn under pressure at any time. Holders are made in 3 categories adaptable to various line sizes and survey techniques. Corrosion coupons—available in standard lengths of 3″, 6″, and 8″, in any type of steel or rare metal—may be fully insulated from holders... remain unaffected by external soil conditions.

**WATER SAMPLING SURVEY.** Takes sample of line fluid for analysis. Special Cosasco water sampling plug with extension nipple and fluid catch attachment of S. S. 303 is inserted in Access Fitting body through main valve. An upper S. S. assembly, consisting of a horizontal and vertical run, each with ½″ valve, is installed on the main valve. This permits taking a sample under full pressure and normal operating conditions to determine causes of corrosion.

**THERMOCOUPLE SURVEY.** Tells operator what part temperature is playing in corrosion problem. Cosasco thermocouple plug attachment (S. S. 303) is inserted in Access Fitting body and main valve is removed. Iron constantin wire is then pushed through gage carrier plug into position in the line. Thermocouple can be removed at will or hooked up to chart recorder for continuing temperature check.

**ATOMIC HYDROGEN SURVEY.** Discloses whether free atomic hydrogen is causing internal blistering. Cosasco hydrogen probe is installed through body of Access Fitting ... can be easily withdrawn while vessel or line is on stream. Ball-check safety device protects against blowout or damage to gage should lower end of probe be damaged by excessive hydrogen in line fluid. Probe detects presence of free atomic hydrogen... gages rate of hydrogen diffusion.

**RATE-OF-CORROSION SURVEY.** Gives rate-of-corrosion reading electronically. Cosasco Corrosometer* Probe is installed under pressure through Access Fitting... quickly gives corrosion reading in increments of microinches without removing specimens or interfering with operations. Readings can be made in as little as 30 seconds without withdrawing the probe.

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*If you have a corrosion survey problem, Cosasco can help you solve it. Send details and blueprints and the Cosasco solution will be worked out promptly—at no cost to you.*

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# Four Regional Meetings Scheduled in October

## NATIONAL and REGIONAL MEETINGS and SHORT COURSES

**1958**

Oct. 5-8—Northeast Region. Somerset Hotel, Boston, Mass.

Oct. 15-17—North Central Region. Cincinnati, Ohio.

Oct. 20-24—South Central Region. New Orleans, Roosevelt Hotel.

Nov. 17-19—Western Region. Los Angeles, Statler Hotel.

**1959**

Jan. 12-14—Canadian Region. Montreal, Quebec.

Feb. 11-13—Canadian Region. Calgary, Alberta.

March 16-20—15th Annual Conference and 1959 Corrosion Show. Sherman Hotel, Chicago.

Sept. 29-30, Oct. 1—Western Region Conference. Bakersfield Inn, Bakersfield, Cal.

Oct. 5-7—Northeast Region. Lord Baltimore Hotel, Baltimore, Md.

Oct. 12-15—South Central Region Meeting, Denver, Col.

Oct. 20-22—North Central Region, Cleveland.

**1960**

March—16th Annual Conference and 1960 Corrosion Show. Dallas, Texas, Memorial Auditorium.

Oct. 11-14—Northeast Region Meeting. Huntington, W. Va.

Oct. 25-28—South Central Region Conference, Mayo Hotel, Tulsa.

**1961**

March—17th Annual Conference and 1961 Corrosion Show. Buffalo, N. Y., Hotel Statler.

Oct. 24-27—South Central Region Conference, Houston, Shamrock Hotel.

**1962**

March—18th Annual Conference and 1962 Corrosion Show. Kansas City, Municipal Auditorium.

October 16-19—South Central Region Conference, San Antonio, Texas.

### SHORT COURSES

**1958**

Nov. 10-14. Corrosion Short Course. Key Biscayne Hotel, Miami. Miami and Jacksonville Sections, NACE.

Nov. 20-21—Los Angeles Section. Corrosion of Underground Structures.

**1959**

March 31-April 12. Corrosion Control Short Course. University of Oklahoma-Central Oklahoma Section. North Campus, University of Oklahoma, Norman.

June—Teche Section. Corrosion Control Short Course.

## NACE Membership No. 10,000 Issued

Claude J. Riddle, Douglas Aircraft Co., Inc., Torrance, Cal. has been issued NACE membership No. 10,000. Mr. Riddle's membership was assigned this number exactly 14 years, 6 months and 19 days after issuance of membership No. 1 to R. A. Brannon, Humble Pipe Line Co., Houston on February 10, 1944.

Riddle

During the years since the first membership was issued more than 4000 members have dropped out of the association, while as of August 31 this year 5903 remain members in good standing.

Member No. 10,000, Mr. Riddle, plant engineering supervisor since 1951 in one of Douglas' aluminum fabrication plants, is a native of Kansas City, Mo. After working in the construction business as a surveyor, estimator and draftsman for several years he went with North American Aviation in Kansas City as a tool designer, was tool engineer for Fairchild Aircraft in Hagerstown, Md. and moved to Los Angeles at the end of World War I, where he started his own business designing houses and commercial buildings.

He was employed by Douglas in 1950 in its plant engineering department.

## SECTION CALENDAR

**Oct.**

15 Metropolitan New York Section. In New York City. Underground Corrosion by Microbiological Action, F. E. Kulman.

28 Panhandle Section.

**Nov.**

4 Shreveport Section, Caddo Hotel. Fellowship hour, 6 pm. Deep Ground Beds for Protection of Transmission Lines.

10 Kansas City Section. Corrosion in the Chemical Industry, Ralph Miller, Spencer Chemical Co.

12 Metropolitan New York Section. In Newark. Marine Corrosion Panel—F. J. McGinity, leader.

20 Kanawha Valley Section.

25 Panhandle Section.

## San Joaquin Section

J. A. Bessom, Richfield Oil Corp., Bakersfield, is now secretary-treasurer for San Joaquin Section. He assumed the post when R. J. Kreps was transferred to San Francisco.

## *Over 120 Technical Papers Scheduled For NACE Sessions*

Four regional meetings will be held this month. One regional meeting will be held in November. The five meetings will have more than 122 technical papers and numerous other discussions and panel sessions. More than 30 meetings of technical committees will be held.

These sessions climax a summer filled with preparations by the officials and authors in the several programs and represent a new peak of fall activity for the National Association of Corrosion Engineers.

In addition to the technical programs, numerous other technical and social events are planned. Also to be held are meetings of regional committees. Western Region will follow its conference with a corrosion control short course.

The schedule of meetings is as follows, together with notes on the location of the complete programs published in CORROSION:

Oct. 5-7—Southeast Region, Hotel Jefferson, Richmond, Va. See Page 86, September CORROSION.

Oct. 5-8—Northeast Region, Hotel Somerset, Boston. See Pages 80-81, August CORROSION for abstracts and biographies and Page 92, September for program roundup.

Oct. 15-17—North Central Region, Sheraton Gibson Hotel, Cincinnati. See Page 76, September CORROSION for program roundup, abstracts and biographies.

Oct. 20-24—South Central Region, Roosevelt Hotel, New Orleans. A roundup of the program, including social events, technical program, committee meetings, abstracts and biographies will be found beginning on Page 69, September CORROSION. A list of exhibitors at the exhibition to be held October 21-23 will be found on Page 76, August. A news story in this issue tells about a scheduled meeting of the region's education committee.

### Western Region Sessions

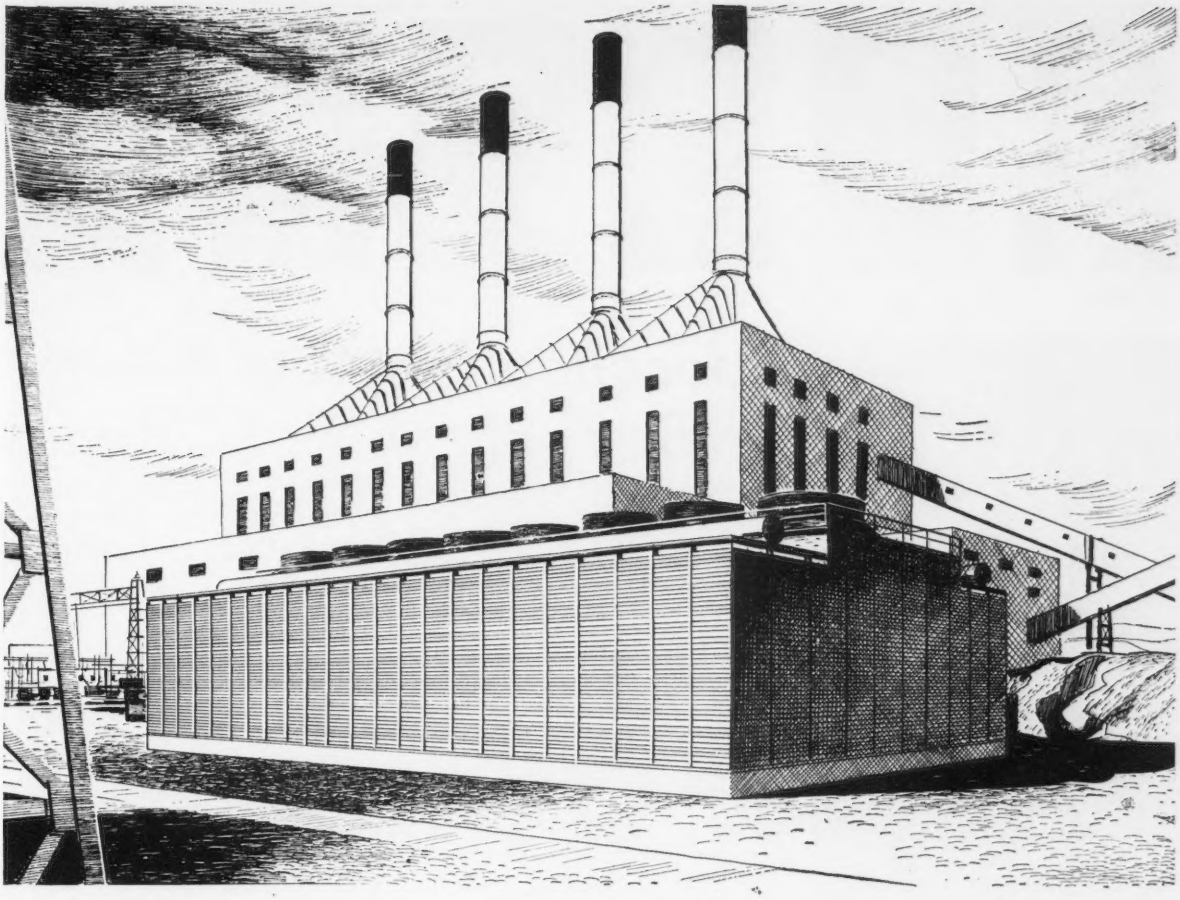
The tentative and incomplete program for the Western Region conference appears on the first page of the NACE News section in this issue. The conference will be held November 17-19 at Los Angeles' Statler Hotel.

The short course on Corrosion of Underground Structures will be held November 20-21 at the Standard Oil Co. Rod and Gun Club, Los Angeles.

Canadian Region has scheduled a dual meeting, one at Montreal January 12-14 and the other at Calgary, February 11-13.

## Coatings for Pipelines Is Topic at Los Angeles Section

Coatings for Pipe Line Protection was the technical subject scheduled for the Los Angeles Section meeting, September 17. V. L. Greedy, sales manager, Pipe Linings was the speaker. Meeting place selected was the Rodger Young auditorium, with a dinner at 7 pm and the program an hour later.



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Calgon* is used to control destructive corrosion in tubing and heat exchangers, even at elevated temperatures. Provision is made for the control of organic growths and for the protection of cooling towers, as well. In each case, treatment is set up to protect the entire system.

Many years of experience with industrial water problems in all parts of the country is the reason why Calgon Engineering Service can provide reliable protection for your plant. A letter or phone call will put one of these experts to work for you.

*Calgon is the Registered Trademark of Calgon Company for its sodium phosphate glass (sodium hexametaphosphate) products. The use of polyphosphates for the prevention of corrosion is covered by U. S. Patent 2,337,856.

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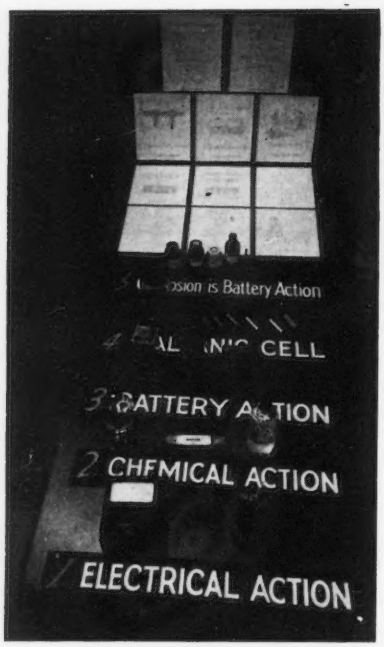


**CORROSION DEMONSTRATION kit for high school use prepared by members of Houston Section NACE for the South Central Region Education Committee. This kit was displayed at the Oklahoma City regional conference in 1957.**

## Corrosion by Cooling Waters Committee Will Convene

Technical Committee T-5C-1, Corrosion by Cooling Waters (South Central Region) will hold a meeting in New Orleans during the week of Oct. 20-24. Industrial experience with different waters and different materials of construction for pumps, valves, lines, heat exchangers and other items will be discussed.

## Publication Committee to Have Session October 20

A meeting of the NACE publication committee has been scheduled for the afternoon of Monday, October 20. It will be held at Hotel Roosevelt, New Orleans during the South Central Region Conference and Exhibition there.

•

NACE now has 56 local sections.

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Corrosion subscribers live in over 40 foreign countries.

# Education Program Results To Be Topic at New Orleans

The role of technical societies in contributing to local science education will be discussed by M. A. Riordan, Texas member, at a meeting of the South Central Region Education Committee October 20 during the annual regional conference at New Orleans. Riordan has devoted considerable time and effort to an investigation of the possibilities of narrowing the gap between local science education and local technical societies. His talk will include the results of discussions with high school science teachers in an effort to develop means of assisting them in accomplishing their educational objectives.

Decisions to be made during the meeting are:

1. Establishment of a policy covering publicity emanating from the committee's efforts.
2. Inauguration of a second corrosion science demonstration kit which will be made available for use in high school science classes.

The South Central Region Education Committee was organized in March, 1955 for the purpose of making a more concentrated effort in promoting educational interests and activity in all phases of corrosion work within the region. Members of the committee are: J. E. Loeffler, Chairman; Thornhill Craver Company, Houston; H. V. Beezley, vice chairman; United Gas Pipe Line Company Shreveport; E. R. Capehart, Kansas representative; Petroleum, Inc. Great Bend, Kansas; E. C. Greco, representative-at-large; United Gas Corp. Shreveport; L. W. Hartkemeier, Colorado representative; Colorado School of Mines, Department of Chemistry, Golden, Col.; J. N. Hunter, Oklahoma representative; Service Pipe Line Company, Tulsa, Okla.; M. A. Riordan, Texas representative; Rio Engineering Company, Houston.

### Functions Are Outlined

Functions of the committee as presently authorized by the regional board are as follows:

1. To investigate the educational needs of the South Central Region.
2. To formulate educational policies for the South Central Region.
3. To co-ordinate educational activities of the local sections and areas in projects of common interest within the South Central Region.
4. To sponsor educational publicity within the South Central Region.

(Continued on Page 78)

### PRIZE-WINNING SCIENCE FAIR EXHIBIT TO BE SHOWN

The prize-winning science fair exhibit of Ludy Harman, Ponca City, Okla. high school student will be displayed at a booth in the South Central Region exhibition to be held in the Roosevelt Hotel, New Orleans. The display is sponsored by the region's education committee, which is working on a program calling for selection of the best corrosion science exhibit by a high school student in the region's 5-state area.

Members of the region's education committee and of the Tulsa, Oklahoma Section, which sponsored Harman will be on hand to answer questions about the education program among young people.

A photograph of the exhibit and young Harman was published in July, 1958 CORROSION on Page 81.

## New Orleans Meeting Committee Changes

Changes have been made in the duties of some officials of the South Central Region Conference in New Orleans. Most of the changes were made necessary by the transfer by his company of W. L. Vorhies, Freeport Sulphur Co. Mr. Vorhies was conference assistant general chairman and chairman of both sessions of the refinery and chemical process industries symposium. Mrs. Vorhies was in charge of the ladies' program.

O. L. Grosz, the California Co., formerly local arrangements chairman, replaced Mr. Vorhies as assistant general chairman. R. M. Eells, Esso Standard Oil Co., formerly co-chairman replaced Mr. Vorhies as chairman for both sessions of the refinery and chemical process industries symposium. A. H. Tuthill, Corrosion Test Supplies Co., assumed Mr. Eells' duties as symposium co-chairman.

New local arrangements chairman replacing Mr. Grosz is C. L. Barr, Shell

(Continued on Page 78)

**Operator checks Ni-Resist pump** at Pennsalt Chemical's Portland plant. This particular unit was manufactured by A. R. Wilfley & Sons, Inc. of Denver, Colorado, and pumps caustic at a concentration of 50%. The Duriron Company, Inc. of Dayton, Ohio, also supplied Ni-Resist pumps for the plant.

# Ni-Resist pump...eleven years caustic service behind it...years of service ahead

Ni-Resist* pumps have been in caustic service at Pennsalt Chemicals Corporation, the Portland, Oregon plant of the Pennsalt of Washington Division, for eleven years . . .

Eleven years of pumping cell liquor containing 9.3% caustic soda at 170°F to evaporator feed storage . . .

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Eleven years of pumping 50% caustic from storage into tanks for shipment.

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NICKEL MAKES ALLOYS PERFORM BETTER LONGER

## Education Program—

(Continued From Page 76)

5. To encourage and command individual action furthering the educational objectives of the South Central Region.

6. To take such other action as the educational committee deems necessary and appropriate to accomplish its educational objectives, provided such action is within the specified jurisdiction of the committee.

In accordance with these functions, the committee has kept in close touch with developments in science education which might contribute to the Committee's work.

### Annual Award Established

To stimulate interest among high school science students in the study of corrosion, an annual award has been established to be given for some outstanding paper or project pertaining to corrosion science prepared by a high school student.

The first such award was made at the regional meeting held at Oklahoma City in 1957 to Stephen H. Caine of Shreveport, Louisiana. His project was a corrosion control demonstrator which consisted of a bank of specimens in a rack above a console, including electrical instruments. Its operation was automatic and keyed to a recorded commentary explaining the fundamentals of corrosion. The education committee sponsored a booth in the exhibit area where young Caine's demonstrator was shown, along with a corrosion science kit developed by members of the Houston Section. The booth attracted wide attention and much favorable comment.

The committee contemplates the preparation of a corrosion short course guide which will outline the overall factors necessary to conduct a short course at the section level. The guide will include a list of materials, suggested methods for the selection of instructors and for setting up committee personnel, list of education publications, information dealing with financing and other such information as may be needed to conduct a section level short course.

### Fellowship Award Studied

Presently, the committee is concentrating its student efforts at the high school level. Plans for the future are to work with colleges in stimulating interest in corrosion science and in establishing specialized courses in the subject. The establishment of a student fellowship award for this purpose is being considered.

Although it is the purpose of this committee to be guided by policies of the National Education Committee, its activities are strictly intra-regional in nature. All expenditures made by the committee are from funds of the South Central Region and are disbursed as approved by the regional board. No direct activities outside the jurisdiction of the South Central Region are contemplated. It is anticipated that a concentrated effort by this committee, with the help of all other members of the region, will result in substantial progress toward promoting further interest and developments in corrosion control.

## Free Afternoon Set for New Orleans Exhibition

The afternoon of Wednesday, October 22 will be free of conflicting activities during the South Central Region Conference at Hotel Roosevelt, New Orleans so registrants may visit the exhibition. The exhibit will be open Tuesday, Wednesday and Thursday, October 21-23, from 10 am to 5 pm.

In addition to the firms listed in the August issue of CORROSION, Cathodic Protection Service, Houston has reserved space, bringing to 26 the number of exhibitors.

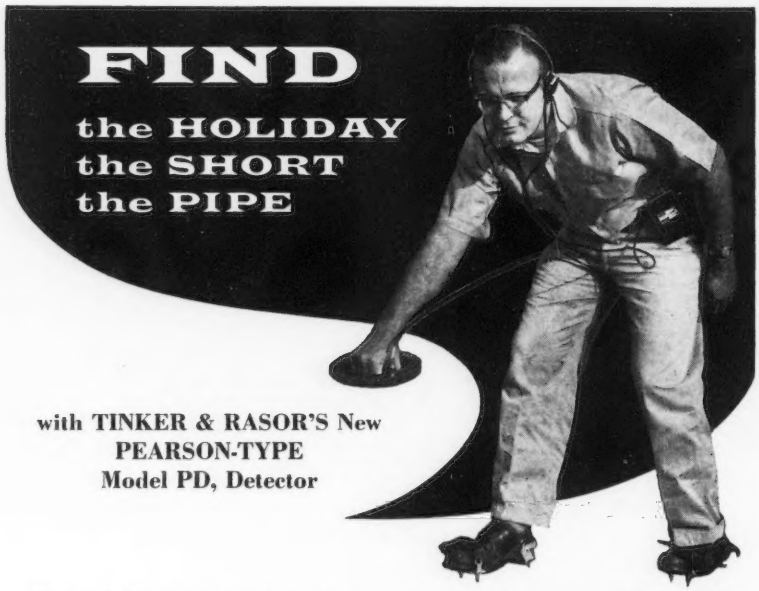
## New Orleans Committee—

(Continued From Page 76)

Oil Co. Mrs. J. W. Redden is now in charge of the ladies program.

A change in one paper in the October 23 morning session of the Oil and Gas Production symposium also has been announced. The paper, "Crude Oil Adherence Tests for Oil Well Corrosion Inhibition," by R. Weiland, Shell Development Co., Emeryville, Cal. and John R. Bruce, Shell Oil Co., Tulsa, Okla. will replace "Correlation of Oil Soluble, Water Dispersible Inhibitors in Sweet Oil Systems," by C. C. Nathan.

The paper, Correlation of Oil Soluble, Water Dispersible Inhibitors in Sweet Oil Systems which was to be presented in the October 23 morning session of the Oil and Gas Production symposium has been withdrawn.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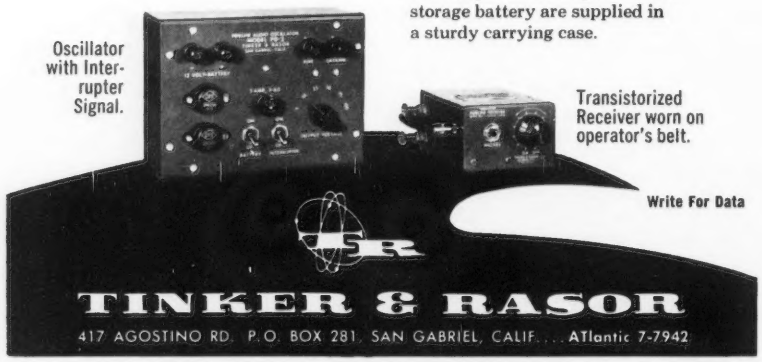
All components except oscillator storage battery are supplied in a sturdy carrying case.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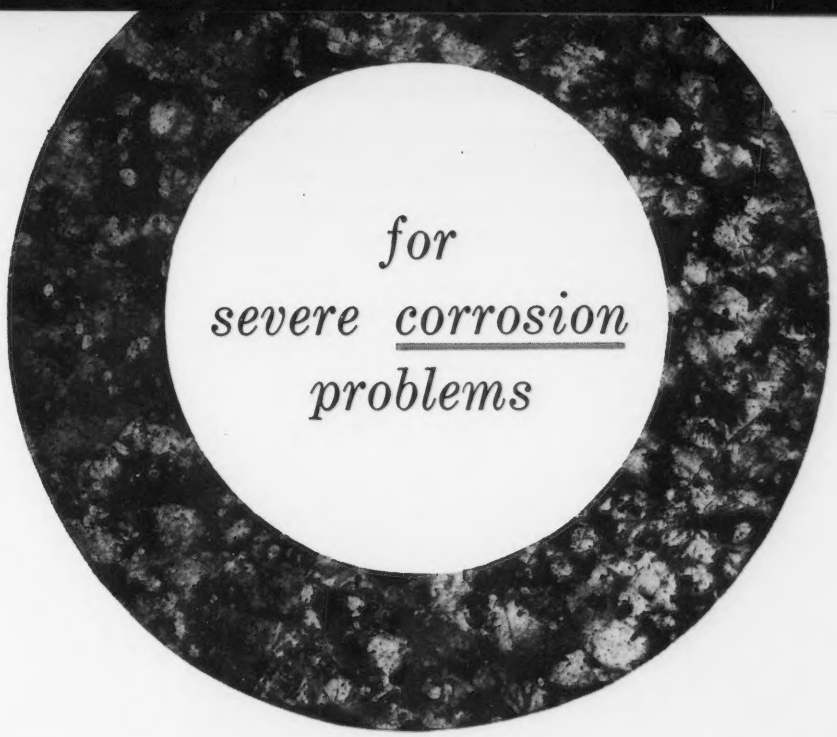


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# Procedure in Selection of Persons to Receive Whitney and Speller Awards

**Procedure in the Selection of Persons to Receive the Willis Rodney Whitney and Frank Newman Speller Awards as Approved by the Board of Directors, December 4, 1953 and Revised March 6, 1955 and December 7, 1957.**

The Board of Directors of the National Association of Corrosion Engineers in a regular meeting on January 17, 1947 authorized the presentation annually of two awards by the Association:

The Willis Rodney Whitney Award is given in recognition of public contributions to the science of corrosion. A contribution to science is defined as the development of new information or the development of a more satisfactory theory which contributes to a more fundamental understanding of corrosion phenomena.

The Frank Newman Speller Award is given in recognition of public contributions to corrosion engineering. A contribution to engineering is defined as the development or improvement of a method, apparatus or material by which the control of corrosion is facilitated or made less costly.

Not later than January 1st of each year, the President in consultation with the immediate past President shall appoint an awards committee. This committee shall consist of at least six members with the President serving as Chairman. He shall continue to serve as chairman of the committee for the calendar year and shall present the award to the recipients selected by his committee. In the event the President upon becoming past President should be unable to serve, the President (for the year the award is to be made) shall appoint a Chairman. The other members of the committee should be outstanding members of the Association. Members shall be appointed for a three-year term with two members being replaced each year. Any member who is lost through resignation or for any other reason, shall be replaced by appointment by the President of the Association.

The Chairman of the Awards Committee shall arrange to keep reasonably detailed records of the activities and discussions of the Committee. These records shall be made available to succeeding Awards Committees.

The Awards Committee shall meet at the Annual Conference, or in the event the Annual Conference is not held or is held later than June 1st the Chairman shall conduct the committee business by correspondence.

The list of candidates to be considered for the Awards shall include:

A. The names of those proposed by the Chairmen of the Regional Divisions in accordance with the wishes of the members of the Division. Nominations may be made by local sections or may be proposed directly to the Chairman of a Region by individual members. In any case, nominations should be accompanied by an appropriate statement of the basis of the proposal. This statement shall be reproduced and submitted to all members of the Awards Committee. The Committee should have such statement for all nominees to be considered.

Prior to February 1st of each year the Regional Chairman shall forward to the Executive-Secretary all names proposed for awards, accompanied in each case by summaries of the reasons presented in support of each proposal but with no indication of the number of duplicate nominations of any individual. The object of this latter provision is to insure that awards will be made on a basis of accomplishments and other qualifications rather than by any semblance of a popular vote.

Not later than October 1st (or the publication date of the October issue of CORROSION) of each year the Executive Secretary shall notify the membership through publication in CORROSION of their privileges in this regard as set forth here. A similar notice shall be mailed by direct letter to all region and section chairmen by October 1st.

B. Any names proposed by the members of the Committee prior to February 1st of each year.

C. The Committee may review and consider nominees from previous years.

D. All nominations shall be submitted to the Executive Secretary who shall distribute copies to all members of the Committee. Nominations will be closed on February 1st.

At the discretion of the Committee members the resultant list of candidates may be reduced to a workable number by elimination of those known to lack the necessary qualifications.

•

As a basis for further consideration by the Committee, the headquarters staff of the Association shall provide the Committee, through its Chairman, with a record of the contributions of each final candidate in the form of a list of his published papers and other works. Such records available in the headquarters office may be supplemented by additional information on the candidates' qualifications which may be secured by any member of the Committee from other sources, such as friends of the candidates, and especially from the proposers of the candidates who should be asked to provide their reasons for suggesting them and a summary of their accomplishments. Ordinarily, the candidates should not be made aware that they are being considered for awards by seeking such information from them directly.

The required activity of the headquarters staff should be facilitated by appropriate use of the literature abstract filing system.

The list of candidates about whom the headquarters staff is to provide the information described should be sent by the Chairman of the Committee to the Executive Secretary of the Association and to each member of the Committee not later than May 1st.

The information to be provided by the headquarters staff should be sent by the Executive Secretary to the Chairman and each member of the Committee not later than July 1st.

Information secured by any member of the Committee concerning any candidate or candidates should be sent to the Executive Secretary not later than June 15th so that it can be circulated amongst all the members of the Committee not later than July 1st.

Not later than August 1st, each member of the Committee shall submit to the chairman and by copy to each member of the Committee, his first and second choice nominations for each award and shall provide with his nominations, his appraisal of the qualifications of those he is nominating and his reasons for preferring them. If a member of the Committee feels that no award should be given, he should so state by August 1st. Failure to nominate either a first or second choice for either award will not relieve a committee member of the duty of voting on the nominations made by others, or of voting that no award be made if those nominated are not considered satisfactory.

Between August 1st and September 1st, the Chairman shall arrange for a letter ballot election by the Committee of those to be nominated for the Awards. If no decision can be made by the first ballot, then a second ballot shall be taken on those who have received the most and second most votes on the first ballot. In the event of a tie for first place on the first ballot, only those names shall be considered in a second ballot. Similarly, in the event of a tie for second place, these names, plus the first place name, shall be considered on a second ballot. In the event a person is nominated for both awards, his vote for one award shall not be considered in determining his standing in the vote for the other award.

If the Committee should decide that none of those nominated are worthy of the Awards, or if no nominations are received, the Committee may recommend to the Directors that one or both Awards be withheld for reasons to be stated in their report to the Directors.

Recommendations of the Committee shall be reported by the Chairman of the Committee to the Board of Directors through the Executive Secretary not later than November 1st.

In the event that the Committee should be unable to reach a decision on candidates for either or both awards, the Committee shall provide the Board with a list of all those proposed for consideration and the number of votes received by each on

(Continued on Page 81)

## Notes for Guidance Of Awards Committee

A. The Committee shall not recommend the same individual for both awards in any one year.
B. Previous recipient of an award is not eligible to receive the same award again.
C. The recipient of one award is not barred from receiving the other award for some other year.
D. In considering the qualifications of those nominated for awards, the nominee's total contributions should be taken into account and recent activities should not take precedence over the recognized results of earlier work. Other things being equal, awards should be made to the candidates who have been contributing consistently for the longest period.
E. Candidates need not be residents of North America.
F. Candidates need not be members of the National Association of Corrosion Engineers.
G. Awards shall be limited to living persons.
H. Recipients of the Willis Rodney Whitney and the Frank Newman Speller Awards and the recipient or recipients of the Junior Award should be guests at the annual NACE banquet.
I. The President and Vice President of the Association and the Chairman of the Awards Committee should not be considered as candidates for awards.

February 27, 1958

## Procedure in—

(Continued From Page 80)

the last ballot of the members of the committee.

The Board of Directors shall then determine, either in a regular meeting, or by letter ballot, returnable not later than December 1st in each year, whether the recommendations of the Awards Committee are to be accepted and the awards made as proposed. If the Board of Directors do not approve the granting of an award, or awards, as proposed by the Awards Committee, then such award, or awards, will not be made for the year in question. In the event that the awards committee has been unable to reach a decision on candidates for one or both awards, the Board of Directors shall determine by majority vote whether an award (or awards) shall be made and to whom it (or they) shall be granted.

After the Board of Directors have chosen the recipients of the awards, the President of the Association shall notify the recipients not later than December 15th, and shall invite each of them to be present at the annual meeting or other occasion when the awards are to be presented. The Chairman of the Committee shall arrange to have approriate certificates inscribed for presentation to the recipients of the awards and on occasion of any public presentation of the awards he shall present the recipients to the President or whoever may be serving in his stead as Chairman of the meeting, to receive the awards at his hands.

The actions of the Awards Committee shall be confidential and confined to consideration only as outlined in the procedure until such time as the President receives acceptance or rejection from the awardees following his notification to them. After receiving acceptance of an award or awardee, the President shall so notify the Executive Secretary who may publicize the information prior to the actual presentation of the award or awards.


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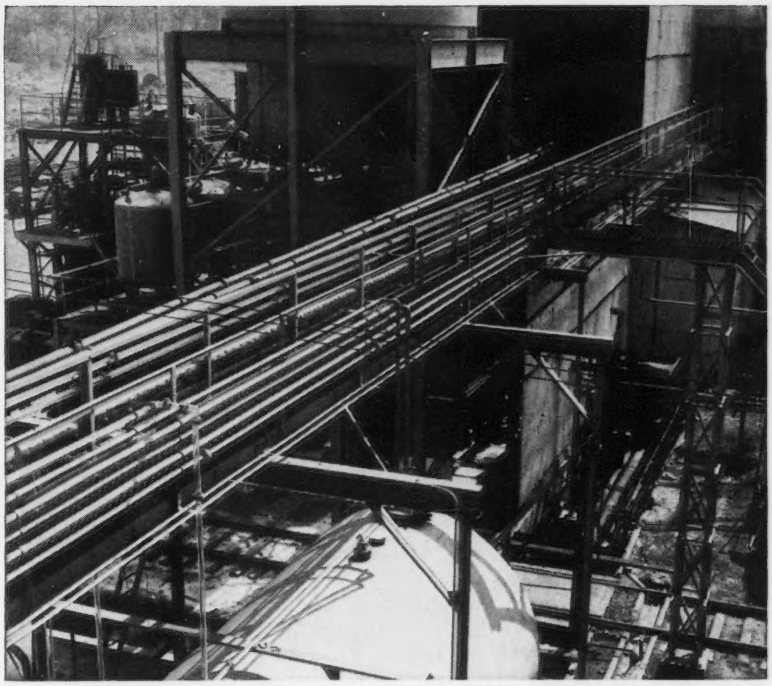

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# Half of 1959 Corrosion Show Space Is Sold

## *Fifty-Six Companies Contract for Booths At Chicago Event*

Approximately half of the available booths have been sold for the 1959 Corrosion Show to be held March 17-19 during the 15th Annual NACE Conference in Chicago.

Corrosion engineers from all parts of North America will gather for the conference and to see the exhibits. The show will be under the same roof as the technical meeting rooms where technical sessions are held. This means that no time will be lost going to and from the exhibition and that those attending technical sessions have quick access to the show at all times. So all attending the conference may examine the exhibits, no technical sessions will be held Tuesday afternoon.

Fifty-six companies had contracted for booths by the first part of September. Classified by general types of industry, they are:

**Cathodic Protection**

American Smelting and Refining Company
Apex Smelting Company
Wayne E. Broyles Engineering Company
Dow Chemical Co., Magnesium Anodes Division
Continental Industries, Inc.
The Duriron Company, Inc.
National Carbon Company
Standard Magnesium Corp.

**Ceramics, Stone, Glass, Cement**

Pfaudler Company

**Ferrous Metals**

The Carpenter Steel Company
Chicago Bridge & Iron Company
Cooper Alloys Corp.
Republic Steel Corporation

**Inhibitors**

Chas. Pfizer & Co., Inc.
Shell Oil Company
Visco Products Company

**Instruments**

Crest Instrument Company
Magnaflux Corporation

**Insulating and Other Pipe Line Equipment**

The Philip Carey Manufacturing Company
Garlock Packing Company
F. H. Maloney Company
Perrault Equipment Co.
T. D. Williams, Inc.

**Non-Ferrous Metals**

Aluminum Company of America
International Nickel Co., Inc.

**Paint, Coatings and Wrappers**

Amercoat Corporation
Bishopric Products Company
Carboline Company
Chicago Metallizing Corporation
Coast Paint & Lacquer Company
Dearborn Chemical Company
Dow Chemical Company, Saran Lined Pipe Division
Dutch Brands, Division, Johns-Manville Sales Corporation
Enjay Company
Kerr Chemicals, Inc.
Metallizing Engineering Company, Inc.
Owens-Corning Fiberglas Corporation
Pittsburgh Coke & Chemical Company
Reilly Tar & Chemical Corporation
Rust-Oleum Corporation
Shell Chemical Corporation
Socony Paint Products Company
Steelcote Manufacturing Company
The Tapecoat Company
Truscon Laboratories
Valdura Division, American-Marietta Company
U. S. Stoneware Co.

**Plastics**

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R. W. Huff, NACE Central Office, 1061 M & M Building, Houston 2, Texas, is in charge of the Corrosion Show.

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## New Orleans Section to Select New Chairman

Selection of a chairman to fill the vacancy left by resignation of William Vorhies was the task of the New Orleans Section. Mr. Vorhies moved to Culver City, Cal.

According to K. J. Ebner, section vice chairman, the section was to decide upon a successor probably at the September 22 meeting. Mr. Vorhies also was active in South Central Region Conference affairs and found it of course necessary to resign his posts there also.

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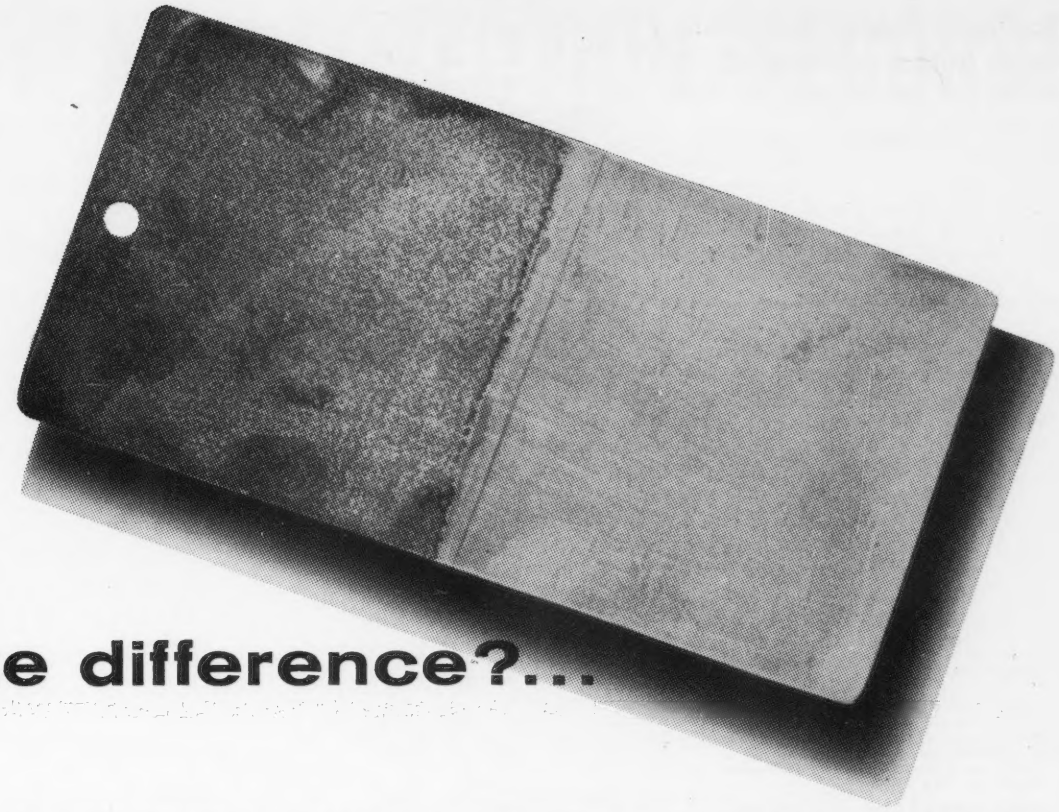

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## Northeast Region Technical Paper Author Is Changed

A change has been announced in the Northeast Region Conference technical program. E. E. Hoffman is the author of a paper in the Utilities Industries and Special Applications symposium titled, "Liquid Metals for Use in a Nuclear Reactor. The symposium will be held on the morning of October 8.


**TECHNICAL REPORTS**

**on**

**CORROSION in UTILITIES**

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**T-4B-2** Cathodic Protection of Cable Sheaths. Fourth Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths. Compiled by Task Group T-4B-2 on Cathodic Protection. Publication 56-13. Per Copy $1.00.

**T-4B-3** Tests and Surveys for Lead Sheathed Cables in the Utilities Industry. Second Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths. Publication 54-6. Per Copy $.50.

**T-4B-4** Pipe-Type Cable Corrosion Protection Practices in the Utilities Industry. First Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths, *Corrosion*, Sept. 54 issue. Publication 54-3. Per Copy $1.00.

**T-4B-6** Stray Current Electrolysis. Fifth Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths, prepared by Task Group T-4B-6 on Stray Current Electrolysis. Publication No. 57-1. Per Copy $1.00.

**T-4B** A Concentrator for Coordinated Corrosion Testing—A Contribution to the Work of NACE Tech. Unit Committee T-4B on Corrosion of Cable Sheaths, by Oliver Henderson and Louis Horbath. Pub. 57-26, Per Copy $.50.

**T-4B** Corrosion of Lead Sheath in Manhole Water—A Contribution to the Work of NACE Tech. Unit Committee T-4B on Corrosion of Cable Sheaths. Pub. 58-6, Per Copy $.50.

**TP-19** Corrosive Effects of Deicing Salts—A Progress Report by Technical Practices Committee 19. *Corrosion*, January, 1954, issue. NACE members $.50; Non-members $1 per copy.

**T-4F-1** Progress Report of Task Group T-4F-1 on Water Meter Corrosion. Per Copy $.50.

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# NACE STAFF

Levy

Welch

Being senior secretary of Central Office and also secretary to T. J. Hull, NACE executive secretary, keeps Durwood Levy busy. Durwood is familiar to many executives and officers of NACE as well as to many others attending NACE conferences. He has acted as recording secretary for many conference meetings of the association's board of directors and executive committee.

He has been with NACE since Feb. 4, 1952, starting his employment as secretary to A. B. Campbell, then executive secretary, NACE. Under recent reassignment of duties, Durwood was given the responsibility of coordinating all stenographic work and personnel. In addition he opens and routes all incoming mail.

He was born at Nolanville, Texas in 1930, and graduated from Belton high school. He attended Hieronymus business school, Temple and Southwestern business university and Rhoades school of business in Houston. His principal hobbies are swimming and music.

Zetta Welch has been with NACE nine years, having begun her duties as secretary to the NACE executive secretary, May 30, 1949. Eight months later she was transferred to the job of membership secretary. Until recently she handled the processing of all incoming mail and subscriptions to CORROSION magazine in addition to processing membership applications.

As membership secretary, Mrs. Welch receives all applications for membership, checks them and writes letters of acknowledgment to new members. On Sept. 2 she received the ten-thousandth application for active membership. She handles the address records for members and sees that address stencils are kept in order. This latter important task requires constant alertness, much checking and letter writing. Last month Mrs. Welch resumed handling CORROSION subscriptions. She is partial to members but likes subscription work because it takes her to all parts of the world in writing the many necessary letters to CORROSION subscribers.

Mrs. Welch was born in Golden Meadow, La. She was educated at Sophie Wright high school and Soule College, New Orleans. Aside from her NACE work she is a housewife, living with her husband Frank near Houston in Genoa where they own their home and some acreage. She likes gardening and has her yard filled with shrubs and trees given to her by friends, making each plant of special interest. On vacations she and her husband make automobile trips to the mountains, especially to national parks. They have been to the Big Bend, Texas; Lincoln National, New Mexico, Yellowstone and Grand Teton, Wyoming; and Rocky Mountain National, Colorado. They have recorded interesting events and sights on their trips on both motion pictures and color slides.

## *New York Section's Programs Are Listed*

Programs have been planned through February 1959 by the Metropolitan New York Section. Meetings will alternate between Newark and New York City to meet the wishes of many section members living near Newark.

First scheduled meeting of the 1958-59 season was for Sept. 17, in Newark. Technical subject selected was Comparative Corrosion Resistance of Titanium and Other Metals, by F. W. Fink, Battelle Memorial Institute, Columbus, Ohio. Mr. Fink is chief of the corrosion research division for the institute. The meeting will be held in Military Park Hotel.

The following schedule of meetings has been planned:

October 15—Underground Corrosion by Microbiological Action, by F. E. Kulman. (New York City meeting.)

November 12—Marine Corrosion Panel led by F. J. McGinity. (Newark meeting.)

December 10—Christmas Meeting. Corrosion of Iron and Steel, by C. P. Larrabee. (New York City meeting.)

January 14—Use of Epoxy Resins in Resistant Coatings, by H. W. Howard, (Newark meeting.)

February 18—High Temperature Corrosion, by E. N. Skinner. (New York City meeting.)

## Typical Corrosion Problems Kanawha Section Topic

Typical Problems in Corrosion and Cathodic Protection was the technical subject scheduled for the Kanawha Valley Section meeting Sept. 18, in Charleston, W. Va. Author of the talk was Bernard Husock, chief engineer, Harco Corp.

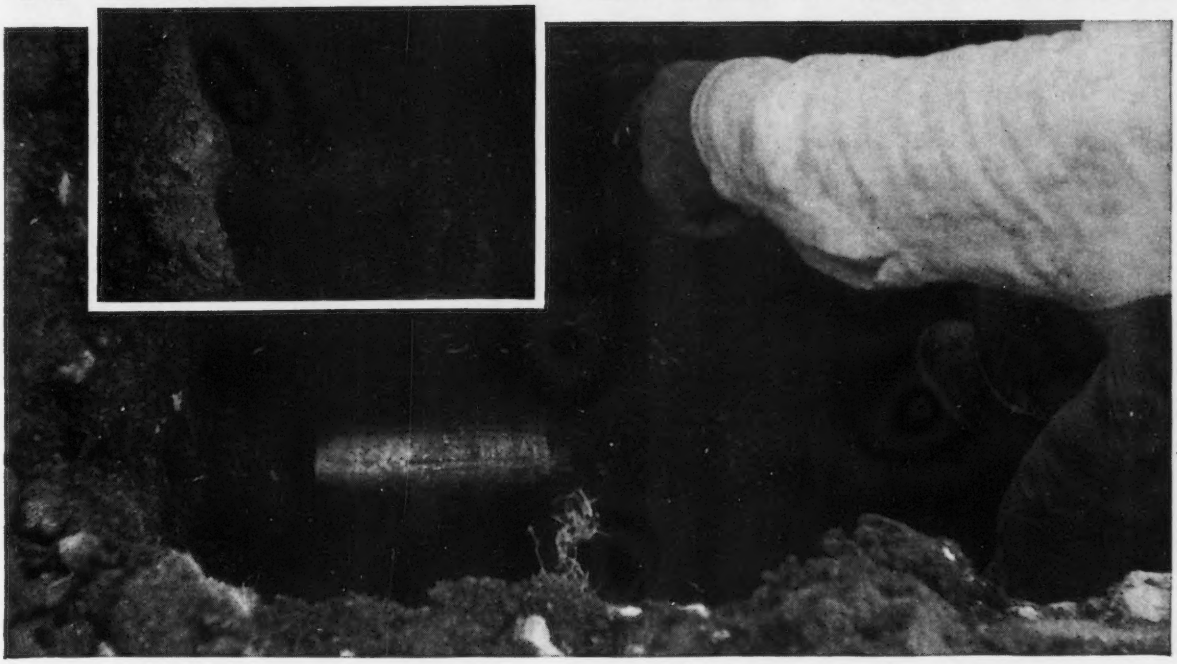
At the May 22 meeting of the section, the Northeast Region Meeting for 1960 tentatively scheduled to be held in Huntington, W. Va. was discussed. The program chairman announced that tentative section program dates for 1958-59 are, November 20, January 22, March 26 and May 21.

Charles Wooddell has been made chairman of the membership committee. Other appointments are: W. W. Matthews, Kanawha Valley Technical Council; R. H. Howell, Engineer Week committee; and George Walther, chairman, nominating committee.

## Trishman Joins Committee

L. E. Trishman, Spang-Chalfant, Ambridge, Pa. has joined the NACE editorial review sub-committee to handle technical papers in the field of ferrous metals.

# 17-YEAR PROTECTION RECORD!



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Since this cost-cutting coal tar coating in tape form was first introduced in 1941, it has demonstrated its ability to withstand severe conditions underground or under water. TAPECOATED lines dug up after 17 years of service show no signs of deterioration on the pipe.

Typical is the experience of a utility in a coastal area. For a thorough trial, this company applied TAPECOAT in areas where severe corrosive conditions were known to exist. The lines were dug up this year and, after years of service under severe conditions such as brackish waters and corrosive soil, the pipe showed no signs of corrosion, proving the quality of TAPECOAT protection.

In terms of preventive maintenance and replacement costs, performances like this emphasize the most important consideration in buying protection. Remember, TAPECOAT is a hot-applied coal tar coating in tape form—designed for lasting protection on pipe, pipe joints, service connections, mechanical couplings, fittings, insulated lines, tanks, tie rods, and other steel surfaces vulnerable to corrosion.

TAPECOAT comes in rolls of various widths and is available in asphalt. Where primer is desired, specify TC Primecoat, the compatible coal tar primer.

A TAPECOAT sales and service engineer is always available to help you on any corrosion problem. Write for complete details today!

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## Changes Made in Southeast Region Technical Program

Two changes have been made in the technical program for the Southeast Region Conference, 5-7. One paper on Combating Tanker Corrosion has been withdrawn. The paper Recent Developments in Coating Materials by Kenneth Tator, Kenneth Tator Associates was added to the symposium Monday afternoon.

The complete program may be found on Page 86, September CORROSION.

## SOUTHEAST REGION BIOGRAPHIES

**JAMES H. BARNETT**—Has been a member of NACE since 1955. At that time he was affiliated with Fulbright Laboratories in chemically treating water to prevent corrosion of industrial equipment, primarily in circulating water systems. He has a BS in chemistry.

**W. ROGER BUCK, III**—Is a senior research chemist at the Virginia Institute for Scientific Research. He received a BS degree in chemistry from the University of Richmond in 1935 and a master's degree in physical chemistry from Duke University in 1940. Before coming to the Institute in 1952 he did college teaching. He is a member of The National Association of Corrosion Engineers, the American Chemical Society, and the Electrochemical Society.

**JOHN F. ECKEL**—His varied experience has brought him close to many corrosion problems, particularly in connection with atomic energy developments where he was confronted with the problem of stress corrosion in stainless steels. Since 1956 he has been head of the department of metallurgical engineering at the Virginia Polytechnic Institute, Blacksburg. He is a native of Kansas, was graduated from the University of Kansas and later did graduate work at the Carnegie Institute of Technology.

**HOWARD T. FRANCIS**—Supervisor of the Electrochemistry Section of the Armour Research Foundation, he received a BS in chemistry from Mount Union College in 1938 and a PhD from Pennsylvania State College in 1942 when he joined the foundation. His fields of interest include corrosion, electrodeposition and batteries with major emphasis on new solutions of electrochemical problems.

**HARRY C. GATOS**—Is associated with the Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Massachusetts. After doing his undergraduate work in chemistry at the University of Athens, Greece, he served for four years as an instructor in the chemistry department of that university. He received an MA in chemistry from Indiana University and a PhD in inorganic chemistry from MIT. Dr. Gatos served for a year as research associate in the department of metallurgy at MIT and then joined the engineering research laboratory, engineering department, E. I. duPont de Nemours and Company, Inc. His main research interests are in the fields of electrochemistry, metallic corrosion and chemistry of metal surfaces.

**HENRY LEIDHEISER, JR.**—Is assistant director of the Virginia Institute for Scientific Research, a laboratory devoted to fundamental research in the physical sciences. Dr. Leidheiser holds the PhD in physical chemistry from the University of Virginia. His research interests are broadly in the field of the surface properties of metals and specifically in the field of electroplating and corrosion.

**THOMAS P. MAY**—Since June 1957 Dr. May has been manager of The International Nickel Co., Inc. Kure Beach-Harbor, Island Testing Station on the North Carolina coast near Wilmington. He had been technical manager of the station since August 1954. He joined Inco at New York in 1947 after 10 years as head of the Corrosion Section, Chemistry Division, U. S. Naval Research Laboratory, Washington. He is a past director of NACE, and has served as chairman of the association's publication committee.

**JOSEPH B. PRIME, JR.**—Is affiliated with the Florida Power and Light Co., Miami. He has been a member of NACE since 1950. He has been engaged in corrosion work for about 10 years, working on design and maintenance of cathodic protection equipment for plant and transmission distribution cables. He has a BS in engineering science from the University of Miami.

**KENNETH TATOR**—Is head of Kenneth Tator Associates, paint consultants. Mr. Tator joined NACE in January 1945. He has had close to 30 years corrosion experience with coatings. From 1930 to 1940 he was affiliated with Dewey & Almy Chemical Co., in charge of production quality control, research and product development and director of the closure research division. He became a chemical consultant in 1940 for Dewey & Almy Chemical Co. and Chemical Industries. During the war he was with the War Production Board and in 1944 founded and was president of Industrial Lining Engineers. In 1949 he became head of Kenneth Tator Associates. He is author of many published articles and papers and holds patents on container linings, plastic products and corrosion barriers.

## Alamo Section Schedules Annual Social Function

A social function "with dancing for those who are able," was planned for the Alamo Section September 16 meeting. Wives were invited as special guests at the meeting. No regular business was scheduled for transaction at the meeting, the purpose of the meeting was "to enjoy good food and good fellowship in pleasant surroundings." A filet dinner was planned with music provided by Zane Morgan's record player. Meeting place was the Grey Moss Inn.

## SOUTHEAST REGION ABSTRACTS

**Metallic Cations and Solid Metals as Corrosion Activators and Inhibitors in Acid Solution** by Henry Leidheiser, Jr., and W. Roger Buck, III. Results of the following three studies, whose objective is to obtain a better understanding of the effect of one metal on the corrosion of another, will be summarized: 1) The corrosion of 15 metals by boiling acids in the presence of low concentrations of metallic cations; 2) the corrosion of 10 metals in boiling HCl as affected by contact with ruthenium, rhodium, palladium, osmium, iridium, platinum, silver and gold; and 3) corrosion and potential measurements on titanium in boiling HCl when contacted to 21 different metals.

**Stress Corrosion Cracking of Stainless Steels** by John F. Eckel.
Some of the known facts that have been accumulated on stress corrosion cracking of stainless steels and current theories on this phenomenon are discussed. Measures which can be taken to minimize danger from this type of corrosive attack and the direction in which future investigations should go are considered.

## Chicago Section Programs for Seven Meetings Outlined

Chicago Section has scheduled seven meetings beginning with September 16 when J. S. Long, Foundation of Paint Research was scheduled to talk on "Some Problems of Modern Living."

Other programs planned are:

Oct. 21—Dresden Nuclear Power Station, J. J. Poer and W. J. Skewski, Commonwealth Edison Co.

Nov. 18—Metallic Coatings, David W. Levinson, Armour Research Foundation. Joint meeting with The Electrochemical Society.

Jan. 20—Bacteria's Role in the Corrosion of Iron, D. M. Updegraff, Minnesota Mining & Mfg. Co.

Feb. 17—A Solution of Joint Electrolysis Problems in Stray Current Areas, Louis Horvath, Ohio Bell Telephone Co.

Apr. 21—How to Paint Tanks Economically, K. R. Walston, Standard Oil Co. (Indiana).

May 19—Corrosion Problems in Water Treatment, John R. Baylis, Chicago City Water Dept.

News from
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## National Carbon representatives expand your engineering force

**L. E. BRUGMANN,**
SALES ENGINEER

Mr. Brugmann was graduated from Purdue University with a B.S. Degree in Chemical Engineering. For three years he worked in the midwest as a process engineer with a large chemical company. His work covered development of new chemical processes and the improvement of existing processes, both from the technical and economical aspects of the process. It was necessary for Brugmann to know the required equipment thoroughly, to work on the design of new equipment and to draft an economic evaluation of any changes.

Mr. Brugmann has been with National Carbon Company since 1954. His first two years were spent in the Cleveland Office working up Engineering Proposals on incoming inquiries from chemical and allied industries. He has been a field engineer covering the west coast since 1956. Call your National Carbon Sales Engineer today.

## "KARBATE" PUMPS HANDLE A WIDE RANGE OF CORROSIVE SERVICES EFFICIENTLY AND ECONOMICALLY

This carload of "Karbate" pumps was shipped to a major rayon producer.

During the past twenty years, "Karbate" impervious graphite pumps have gained an envious performance record corrosion wise. A recent survey on service applications indicates these pumps handle a wide variety of corrosives over a wide temperature range. Some of these solutions are: hydrochloric acid, all concentrations; phosphoric acid — up to 75%; sulphuric acid from 1 to 93%; chlorinated hydrocarbons such as benzene hexachloride, monochloracetic acid, DDT; mixed acids such as nitric-hydrofluoric, sulphuric-hydrofluoric, hydrofluoric-chromic oxide, chromic-nitric hydrofluoric, phosphoric-hydrochloric nitric; chlorinated sodium and potassium chloride brines, ferric chloride; caustic; chlorine saturated water.

The excellent corrosion resistance of "Karbate" pumps permits a given plant to utilize one type pump for all corrosive services. Such a pump standardization means a saving in pump parts inventory, and also means lower maintenance costs due to greater proficiency in handling one type pump.

### "KARBATE" PUMPS FEATURE LOW MAINTENANCE COSTS

A rayon manufacturer reports using "Karbate" impervious graphite pumps to handle rayon spin bath solutions. Maintenance costs on each pump were $25.00 the first year and $25.00 the second year — costs on an alloy pump were $25.00 the first year and *$500.00 the second year.*

A major chlorine producer is using "Karbate" impervious graphite pumps to handle chlorinated cell brines. Eighteen pumps are in service. Maintenance costs on the "Karbate" pumps are approximated at $100.00 per pump per year as compared to costs on another non-metallic type pump of *$500.00 per pump per year.*

• • •

**"KARBATE" PUMP TABLE OF SIZES AND CAPACITIES**

| Pump size Suction | | Discharge | Motor-Mounted Type F | Frame-Mounted Type C |
|---|---|---|---|---|
| 2 | x | 1½ | 29-FAL | 1½-CB |
| 3 | x | 2 | 19-FAL | 2-CA<br>2-CB |
| 4 | x | 3 | — | 3-CA<br>3-CB |
| 6 | x | 4 | — | 4-CA |

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UNION CARBIDE

# Versatility and Good Performance of Epoxy Resins Described at Houston

The versatility and good performance of epoxy resin coatings was demonstrated to the Houston Section at its September 9 meeting by H. W. Howard, Shell Chemical Co., the technical speaker.

Epoxy resins are entirely derived from petroleum, Mr. Howard said. He explained the process by which the material is made. Epoxy resins have a wide variety of properties, being used for coating materials, adhesives, to patch highways and roads, put patches on and to coat pipe lines. They can be combined with glass to provide a tough, highly corrosion-resistant material and can be compounded so thick a trowel is used in applying them or thin enough to be made into paints.

Principal advantage of epoxy paints is the saving in application costs, Mr. Howard pointed out. Self-priming epoxy resin coatings can be applied in thicknesses of eight mils per coat. New equipment has been developed which will spray 100 percent solid epoxy resin materials for coatings.

### Solidifies By Reaction

The epoxy coating is so inert and performs so well that only an hour is required to completely clean contaminating cargo from tank cars used by his firm, Mr. Howard said. The coating does not set by oxidation, but rather through reaction of the epoxy with amines. To demonstrate the reaction, he mixed the syrupy, colorless epoxy resin with dark colored amine. Within seconds, the compound was seemingly rock-hard. Amines have a very strong affinity for epoxy resins, he stated, and paints made of the two will set not only on the surface as in air-setting paints, but uniformly from base to surface, throughout the coating. This prevents "case hardening" with a hardened outer film covering soft paint beneath.

**A MEMBER OF Houston Section discusses coatings with H. W. Howard (right) after the Sept. 9 meeting.**

### Coal Tar Changes Noted

Addition of epoxies to coal tar drastically changes the characteristics of coal tar, he said. Epoxy coal tar coatings will not crack in cold weather, nor run in hot weather, according to Mr. Howard.

In the lively discussion which followed Mr. Howard's talk, one member present pointed out that information on the performance of epoxy coatings for pipelines is not available. Without definite performance data, many engineers are reluctant to use the material, he said. One representative of a firm making the coatings pointed out that the engineer must rely on the integrity of the supplier, and upon his recommendation.

In answer to a question, Mr. Howard said it was true, epoxies were not a complete answer to all corrosion problems. Nitric acids and compounds of nitrogen attack them, he said. Resistance to water he called adequate, except to distilled water, where it is not good. Surfaces either must be dry or be made miscible with the epoxy coatings, he said.

During a brief business meeting, A. B. Campbell, retired NACE executive secretary, announced he is beginning a project to stimulate interest on the part of NACE corporate representatives to get them to attend section meetings and to take an active part in association work.

# Officers Nominated by North Texas Section

Nomination of candidates for office for the North Texas Section was the principal business scheduled for the September 8 meeting of the section.

H. E. Greenwell, Production Profits Inc. was named chairman of the nominating committee; members selected were: Richard B. Bender, Plastic Engineering & Sales Corp., Charles Holland, Jr., Sun Oil Co. and Henry A. Stiff, Jr., The Atlantic Refining Co. The committee scheduled September 15 as the date for mailing names of their selections to section members.

Scheduled speaker for the September 8 meeting was W. M. Longnecker, dean of university life, Southern Methodist university. His topic, Our Scientific Educational Plight—Fact or Fancy, was scheduled to be an appraisal of the true status of our position in the technological race, plus a forecast of what is in store in the field of education for our future engineers and scientists. A short social period, a business meeting, and a speaker for the evening, were planned.

# Tidewater Refinery Toured By Philadelphia Section

Corrosion problems peculiar to each operating unit of a refinery were discussed during a tour of the Tidewater Oil Co. plant, Delaware City, Del. by the Philadelphia Section at its August 19 meeting. The trip included a tour of the refinery, a lunch and a round table discussion of refinery corrosion problems. K. L. Moore and George Ross acted as hosts for Tidewater. Fifty members and guests made the field tour.

•

NACE regional and sectional secretaries who do not have a supply already may get copies of the form "News Report for Corrosion," from Central Office on request. The form helps in providing a complete news story concerning meetings. The news deadline for CORROSION is the tenth of the month preceding month of issue.

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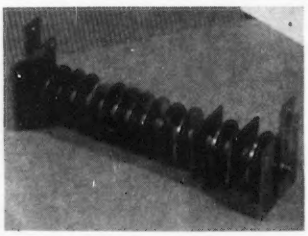

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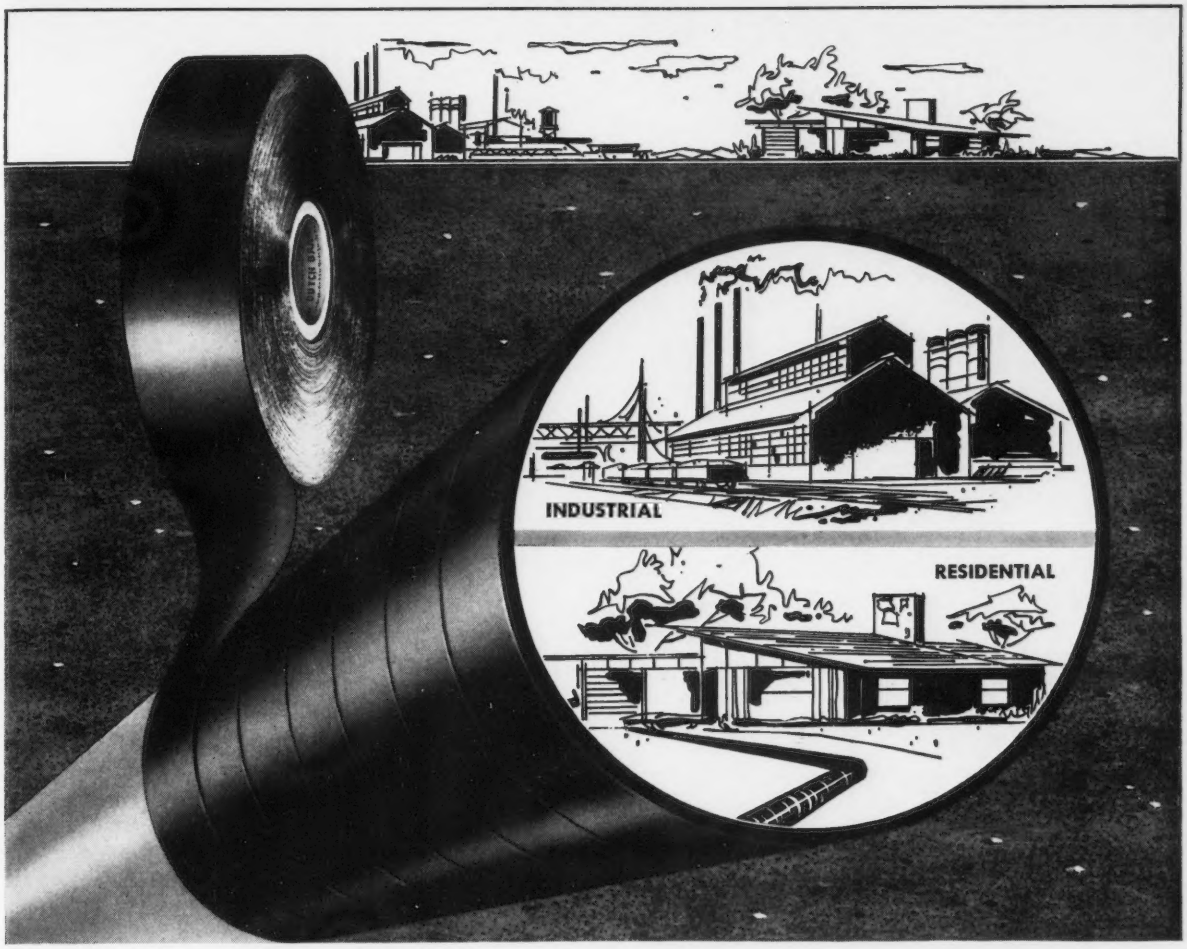
**MEMBERSHIP CARDS NEEDED AT CHICAGO**

**NACE members who are not pre-registered will be required to establish their membership in the association at the 15th Annual Conference in Chicago by showing their membership cards.**

**Registration fee for members is $10; for non-members, $15; for ladies $10.**

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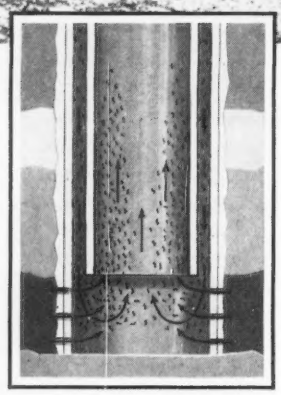

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**CORBAN CORROSION INHIBITOR CUTS WELL MAINTENANCE COSTS.** When corrosion forces operating costs up and profits down, pick the inhibitor that does the job best . . . that's Corban®. Field experience has proved that Corban materially extends the life of tubing, pumps and sucker rods on wells producing corrosive fluids. It helps avoid workovers caused by corrosion-damage. Corban coats all the metal surfaces throughout the well which are contacted by well fluids. It is easy to use—does not aggravate emulsion problems.

Corban, a polar-type inhibitor, comes in several forms: "ready-to-use" liquid, concentrated liquid, and in sticks. Also, it is available in several formulas to meet specific well conditions. Call any of the 165 Dowell service points for a recommendation of the Corban for your wells. In Canada, contact Dowell of Canada, Ltd.; in Venezuela, contact United Oilwell Service. Dowell, Tulsa 1, Oklahoma.

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# Abstracts of Soviet Technical Journals Offered

## ASM Technical Papers Relate to Corrosion

Technical papers to be given during the 40th National Metal Congress of the American Society for Metals at Cleveland's Statler-Hilton Hotel, October 27-30 include:

**High Temperature Metals**

Studies of the Oxidation and Contamination Resistance of Binary Columbium Alloys, C. T. Sims, W. D. Klopp and R. I. Jaffee, Battelle Memorial Institute.

High Temperature Oxidation and Contamination of Columbium, same authors.

**Brittle Fracture**

Low Temperature Embrittlement of Austenitic Cr-Mn-N-Fe Alloys, F. W. Schaller, Case Institute of Technology and V. F. Zackay, Ford Motor Co., Dearborn, Mich.

**Titanium**

Effects of Microstructure and Heat Treatment on the Hydrogen Embrittlement of Alpha-Beta Titanium Alloys, R. I. Jaffee and D. N. Willimams, Battelle Memorial Institute.

Effect of Composition on the Hydrogen Embrittlement of Alpha-Beta Titanium Alloys, R. D. Daniels, University of Oklahoma, Norman; R. J. Quigg and A. R. Troiano, Case Institute of Technology.

Corrosion, Pyrophoricity and Stress Corrosion Cracking of Titanium Alloys in Fuming Nitric Acid, John B. Rittenhouse, Jet Propulsion Lab., California Institute of Technology, Pasadena.

**Metals and Fabrication Methods for High Pressure Applications**

New Welding Techniques in Pressure Vessels, R. E. Lorentz, W. B. Bunn and C. T. Ward, Combustion Engineering Inc.

Heat Treatment of Weldments, Norman Block, Foster Wheeler Corp.

**Residual Stresses**

During the Seminar on Residual Stresses October 30-Nov. 1 the following topics will be discussed: Definition and origin of residual stresses, measurement, influence on deformation, static strength and dimensional stability; influence on fatigue strength and stress corrosion cracking, relation between residual stresses and brittle fracture and methods for stress relieving.

## Polymer Properties Covered

Relation Between Molecular Structure and Polymer Properties was the title of a talk scheduled to be given at the September 23 meeting of the Midlands Coatings Society in the Research Auditorium, Dow Library, Midland, Mich.

**COLUMBIUM APPROVED NAME FOR ELEMENT 41**

Columbium has been adopted as the official name of Element 41 by the American Institute of Mining, Metallurgical and Petroleum Engineers. The institute adopted the name instead of the alternate "niobium" on the basis of an investigation in which it was determined that the element, first found in Massachusetts and announced before a meeting of the Royal Society, London by Charles Hatchett on Nov. 26, 1801 should be called by the name given it first by Hatchett.

The controversy over the name arose from an erroneous assumption by Ekeberg in Sweden in 1802 that columbium and tantalum were the same. The name "niobium" was given to Element 41 by a researcher, H. Rose, in resolving Ekeberg's error when Rose assumed he had discovered a new element.

## Epoxies and Urethanes to Be Topics at Cleveland

New Developments in Epoxy and Urethane Coatings is the topic of a panel discussion scheduled on the morning of October 7 during the 36th Annual Meeting of the Federation of Paint and Varnish Production Clubs. The federation meets October 5-8 at Cleveland Public Auditorium.

Other items to be given include:

Film Thickness on Structural Steel, G. G. Schurr and Wouter Bosch.

Water Thinned Paints for Industrial Use, a panel moderated by R. D. Hamilton, Ford Motor Co.

Statistics as a Tool for Solving Paint Problems, a panel moderated by J. W. Prane, National Lead Co.

## Nondestructive Testing Papers Are Scheduled

Among the papers scheduled for presentation during the October 26-31 meeting of the Society for Nondestructive Testing at Hotel Manger, Cleveland are:

Eddy Current Measurements of Metal Thickness and Cladding Thickness, R. A. Nance and J. W. Allen, Oak Ridge National Lab.

Ultrasonic Weld Inspection, John E. Bobbin, Sperry Products, Inc. Some Recent Advancements in Gaging and Nondestructive Testing with Radioisotopes, Oscar M. Bizzell, Atomic Energy Commission, Washington.

## Offering Complete Translations Due By OTS Center

A Foreign Technical Information Center is now being operated by the U. S. Department of Commerce to provide translations of Soviet technical information. It is a function of the Office of Technical Services, Business and Defense Services Administration, Washington, D. C.

Services of the center include publication of abstracts of all articles appearing in 141 Soviet technical journals, translations of important sections of REFERATIVNVY ZHURNAL (an abstract journal) and a semi-monthly review of various areas of Soviet science compiled by the Central Intelligence Agency.

Abstracts of each issue of the 141 journals may be purchased from OTS on a subscription or a single issue basis as may CIA's SCIENTIFIC INFORMATION REPORT. Various sections of the Soviet abstract journal will be sold initially by single issues, but subscriptions may be offered later.

OTS also plans to begin distributing complete translations of articles and books, which will be listed in an abstract journal, publication of which is scheduled to begin in September.

The volume of material collected so far is estimated to run at 50,000 abstracts and 10,000 complete translations a year. The center also plans later to add material from other sources and develop a central point to which science and industry may look for Soviet bloc developments. The information program is operating on an appropriation from Congress of $510,000 for fiscal 1959.

Among the publications available are:

Scientific Information Report, semi-monthly, $28 a year; $2.75 a copy.

Russian Abstract Journal. Translations of physics series available, prices on request.

English abstracts on cards are available of articles from the following publications on a subscription basis at prices indicated or at 50¢ per set: Civil Aviation, $6 a year.

News of the Institutes of Higher Learning of the Ministry of Higher Education, USSR. Aircraft Construction, quarterly, per year, $2.

Wings of the Nation, monthly, per year, $6.

Herald of the Air Fleet, monthly, per year, $6.

News of the Academy of Sciences of the USSR. Mathematics Series, bi-monthly, per year, $3.

News of the Academy of Sciences of the USSR, Dept. of Chemical Sciences, monthly, per year, $6.

News of the Institutes of Higher Learning of the Ministry of Higher Education, USSR. Chemistry and Chemical Technology, bi-monthly, per year, $3.

(Continued on Page 92)

## Industrial Coatings on NPVLA Agenda Dec. 3-4

A special group of talks on paints and coatings for industrial requirements will be a feature of the December 3-4 conference sponsored by the National Paint Varnish and Lacquer Association. The conference will be held at Hotel Shoreham, Washington, D. C.

Another session is scheduled on paint maintenance with papers to be given including:

Paints and Coatings for High Humidity Service and Mechanical Equipment, C. W. Shay, E. I. du Pont de Nemours & Co., Inc.

Special Paints and Coatings for Industrial Requirements: High Humidity Applications, Merton E. Williams, The Wilbur & Williams Co.; High Temperature Applications, Milton Glaser, Midland Industrial Finishes Co.; Severe Chemical Applications, Kenneth Tator, Kenneth Tator Associates.

Effects of Color on Paint and Coating Performance, W. G. Vannoy, du Pont.

Panel discussion on the Economics of Paints and Coatings, Frank Scofield, National Paint Varnish & Laquer Assoc., chairman.

## Brussels Program Includes Three Papers on Corrosion

Three papers on corrosion problems were on the program for the September 22-26 International Congress for Heating and Air Conditioning held at Brussels:

Corrosion, Scale and Their Prevention in Heating and Air Conditioning Installations, A. de Grave, General Inspector of Buildings, Public Works Ministry.

Corrosion of Underground Pipes for Hot Water Heating, N. C. Geertsen, Danish National Institute of Building Research.

Prevention of Gas Side Corrosion in Oil Fired Heating Boilers, K. H. Sambrook and R. W. Kear, Oil Products Development Dept., Shell Petroleum Co. Ltd., Great Britain.

# BOOK NEWS

**Corrosion of Oil and Gas Well Equipment.** 48 pages, 8 x 11 inches, paper. Maps, charts and photographs. Scheduled for publication September 1958. American Petroleum Institute, 50 West 50th Street, New York 20, N. Y. Per copy, $2.50.

The book is a manual compiled for field operating personnel. It is intended for use by foremen, pumpers, well tenders and others. Purposes of the manual are: 1. To present to operating personnel the tremendous cost of corrosion. 2. To enable them to recognize early indications of corrosion. 3. To emphasize the importance of early reporting. 4. To encourage field personnel to take an active part in solution of corrosion problems.

The manual uses simple terms and descriptions. It is not intended for use as an advanced text by corrosion scientists and engineers. Control measures it describes are of a general, typical nature, not intended to be a guide for use in specific cases.

Chapter One of the manual deals with the general aspects of corrosion, giving the general types of corrosion, the economic aspects, and the importance of field personnel in corrosion control programs.

Chapter Two concerns sweet oil corrosion. Chemistry of corrosion is given, as is also a description of the different types of corrosion damage to various apparatus and well installations. Gas-condensate and oil wells are both considered. Methods for evaluating the extent of corrosion are described and general kinds of preventive measures and procedures are given.

One chapter deals with sour oil corrosion. Although the problem is different, the method of presentation in the manual is like that used in Chapter Two explaining sweet oil corrosion.

## Abstracts of—

(Continued From Page 91)

Chemical Science and Industry, bi-monthly, per year, $3.

Chemical Industry, 8 issues yearly, $4.

Chemistry and Technology, Fuels and Oils, monthly, per year, $6.

Progress of Chemistry, monthly, per year, $6.

Journal of Physical Chemistry, monthly, per year, $6.

Journal of Inorganic Chemistry, per year, $6.

Journal of Applied Chemistry, monthly, per year, $6.

Journal of Abstracts, Chemistry, semi-monthly, per year, $12.

Electric Power Stations, monthly, per year, $6.

Atomic Energy, monthly, per year, $6.

Power Engineering Bulletin, monthly, per year, $6.

The Petroleum Worker, monthly, per year, $6.

Petroleum Economy, monthly, per year, $6.

Industrial Power Engineering, monthly, per year, $6.

Construction of Enterprises of the Petroleum Industry, monthly, per year, $6.

Heat Power Engineering, monthly, per year, $6.

Physics of Metals and Metallography, bi-monthly, per year, $3.

News of the Institutes of Higher Learning of the Ministry of Higher Education, USSR. Nonferrous Metallurgy, bi-monthly, per year, $3.

Metallurgist, monthly, per year, $6.

Steel, monthly, per year, $6.

Welding Practice, monthly, per year, $6.

Nonferrous Metals, monthly, per year, $6.

Journal of Abstracts, Metallurgy, monthly, per year, $6.

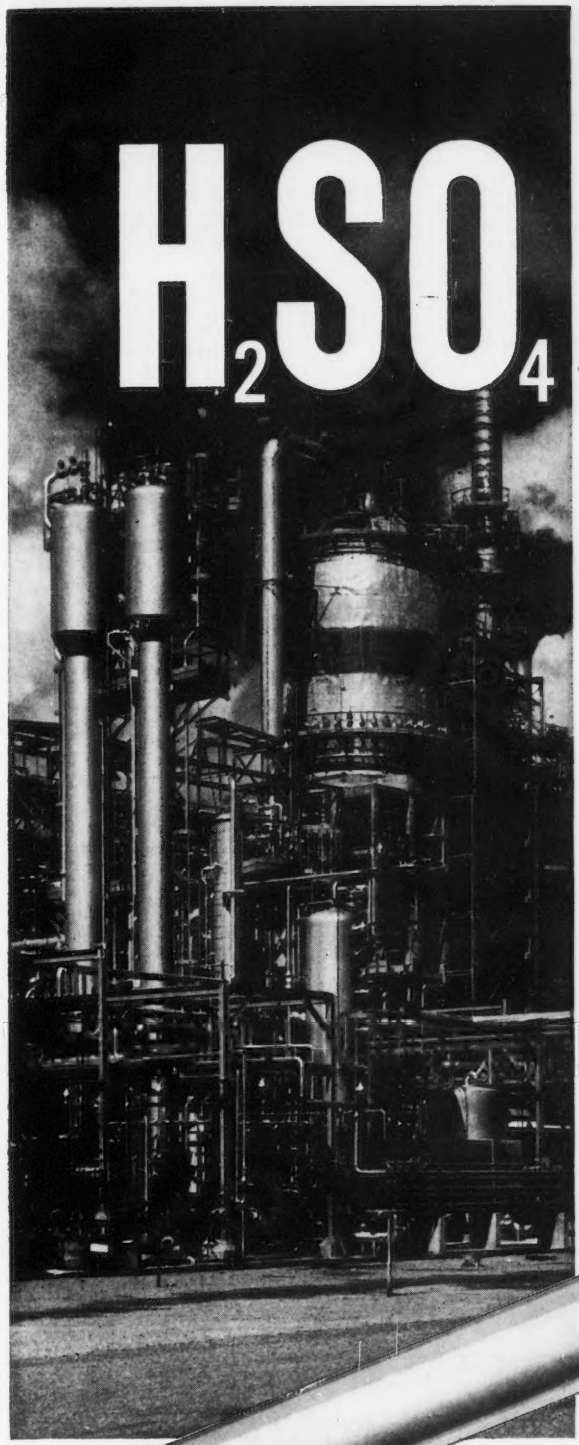
Progress of the Physical Sciences, monthly, per year, $6.

Journal of Technical Physics, monthly, per year, $6.

Journal of Abstracts, physics, monthly, per year, $6.

## Titanium Symposium

The Seventh Annual Titanium Symposium of the Metallurgical Society of the American Institute of Mining, Metallurgical and Petroleum Engineers will be held October 28. The symposium is one feature of the institute's program at its annual fall meeting, October 27-30, at Cleveland's Carter Hotel.

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## TEFLON® liner in thermal equilibrium with housing

Sulfuric, hydrochloric, nitric, hydrofluoric—*any* acid is harmless to Fluoroflex-T piping.

**Universally inert liner.** Steel pipe and fittings are lined with Fluoroflex-T . . . a patented, high density, *non-porous* compound of Teflon.

**Liner and housing are in thermal equilibrium** through an exclusive process developed by Resistoflex. It compensates for thermal expansion differential between the Teflon and the pipe housing, eliminating fatigue collapse, and cracking at the flange.

**Solves problems, saves downtime, saves money.** Type S piping installed in steam cooking process for recovering sulfuric acid from coal tar sludge at 250°F and 50 psi has been in service over a year with no maintenance difficulties.

See how Fluoroflex-T Type S piping systems can end problems of corrosion, erosion and contamination for you. Send for detailed Bulletin TS-1A. Dept. 133, RESISTOFLEX CORPORATION, Roseland, New Jersey. Other Plants: Burbank, Calif., Dallas, Tex.

*® Fluoroflex is a Resistoflex trademark, reg., U. S. pat. off.*
*® Teflon is DuPont's trademark for TFE fluorocarbon resins*

# RESISTOFLEX

*Complete systems for corrosive service*



LINED STEEL PIPE • FLANGED FLEXIBLE HOSE • BELLOWS • ELBOWS • TEES • REDUCERS • DIP PIPES & SPARGERS • LAMINATED PIPE

# Equipment Services NEW PRODUCTS Materials Literature

## Alloys

**Rene 41,** a precipitation hardening nickel base alloy with high strength in the 600-1800 F range has been developed by General Electric Company's Metallurgical Products Dept.

## Aluminum

**Alcoa Aluminum Rigid Conduit,** an 8-page and cover illustrated brochure gives installation and specification information on conduit. Copies are available from Alcoa sales offices or 749 Alcoa Bldg., Pittsburgh 19, Pa.

•

**L-Shaped Extrusions** are available for use as bus conductors adaptable to normal cable lug connectors. Designed as a low-cost substitute for tubular bus conductors, the extrusions are marked with shallow longitudinal grooves which locate center points for drilling holes to receive standard connectors.

## Anodes

**Zinc Anode suppliers'** names are sought by American Zinc Institute, 60 East 42nd St., New York 17, N.Y.

## Boilers

**Stainless Steel** tubes have been installed in the Monongahela Power Company's Rivesville Station in West Virginia. Allegheny Ludlum Steel Corp. supplied 9234 tubes for the Unit 6 condenser of this plant. Condensing surface area is 55,000 sq. ft.

## Chelating Agents

**Imperial Chemical Corp.,** 6505 Wilshire Blvd., Los Angeles 48, Cal. offers a new chelating agent derived from cadavarine, isolated from putrefaction of animal proteins, which when used in ion exchange systems results in high selecticity for copper and certain other metal ions by the resin. Because calcium is no longer absorbed, capacity of the resin for copper and zinc is increased.

## Coatings—Organic

**Becco Chemical Div.,** Food Machinery & Chemical Corp., Station B, Buffalo 7, N.Y. announces development of two diepoxides designed for use in epoxy and other resin systems as diluents, cross-linking plasticizers or modifiers. Dicyclopentadiene Dioxide is described in Bulletin 95 and Limonene Dioxide in Bulletin 96.

•

**Impervious Coatings** giving graphite excellent oxidation resistance and adhesion characteristics have been developed in the Nuclear Research Section of Minnesota Mining & Mfg. Company's research laboratory. A new process for bonding graphite also was announced by the company. Various graphite shapes coated by the new process have been subjected to temperatures from 1800 to 2700 F for several hundred hours without any measurable oxidation of the graphite. They also have been immersed in boiling acids (including Aqua Regia) for weeks without damage and exposed to 1600 F steam and carbon dioxide (in separate tests) for several hundred hours without damage. American Lava Corp., Chattanooga, Tenn. will handle commercial production.

## Coatings—Metallic

**Copper Wire** clad with a chrome alloy developed by Sylvania Electric Products Inc., Warren, Pa. is recommended for use as electrical conductors on equipment operating under high temperature, corrosive or oxidizing conditions. Oxygen-free high conductivity copper is inserted into a chrome-iron alloy tube and subsequently cold drawn and annealed to produce a bond. Operating range of the conductors so coated extends to 1300 F.

## Ferrous Metals

**Airsteel X-200,** a new ultra high strength alloy sheet steel for missiles and rockets, has the advantage over other similar materials in that it is air hardenable. Most other alloy steels in its strength range (280,000 psi) require elaborate oil or salt quenching to develop equivalent mechanical properties, according to United States Steel Corp., developers.

•

**Washington Steel Corp.,** Washington, Pa. describes its MicroRold special purpose stainless steels in 28-page and cover booklet. The various steels' applications are described and pictured and tabulated data are given on physical characteristics. Corrosion resistances are tabulated on a scale of 1 through 5 against a wide range of chemicals, foods and temperatures.

•

**Temcombing,** a continuous process of fabricating stainless steel sandwich at a brazing cycle time of from 3 to 20 lineal inches a minute has been developed by Temco Aircraft Corp., P. O. Box 6191, Dallas 2, Texas. It will produce panels up to four feet in width and 10 feet or more long. Single curved contours are produced with ease.

## Filters

**Millipore** cellulose ester membranes installed as filters in distilled or demineralized water systems removes particulate matter down to 0.45 micron, according to Barnstead Still and Sterilizer Co., Lanesville Terrace, Boston 31, Mass.

•

**Dynel Filter** cloth used to hold titanium sponge while it is being spun dry in the centrifuge at speeds up to 500 rpm endures 600 process cycles before replacement compared to 24 cycles of other materials. National Filter Media Corp., 1717 Dixwell Ave., New Haven Conn. weaves the cloth 26 inches wide and 18 feet long to fit the centrifuge walls.

## Inhibitors

**Alconol-400,** applied by brush, dip or spray to entire electrical systems, precision instruments or their parts, cleans and removes moisture, grease, dirt, grit and oils and simultaneously deposits a protective film which resists moisture, corrosion and fungus growth. It is made by Al-Con Chemical Co., Box 8168, New Orleans 22, La.

•

**Sarkosyl** surfactants, high molecular weight carboxylic acids (or sodium salts) are described in a technical bulletin dated July, 1958 available from Geigy Industrial Chemicals, Saw Mill River Road, Ardsley, N. Y. Numerous applications are listed in foods, cosmetics, as detergents, in solvent degreasing, in protective oils and as a corrosion inhibitor in gasoline, kerosene or other hydrocarbons, where Sarkosyl 0 is effective at concentrations as low as 50 ppm.

## Insulators

**Plymouth Industrial Products,** Inc., 502 Indiana Ave., Sheboygan, Wis. is making a plastic housing, which, after being placed around a pipeline fitting, permits filling the space between the fitting and the housing with a plastic, non-hardening filler.

## Instruments

**Pfaudlertron,** an instrument designed for non-destructive testing of surface continuity in glass steel equipment has been developed by The Pfaudler Co., Rochester, N. Y. When a probe is swept over the surface to be examined, a neon bulb in its Ilucite handle glows to indicate a holiday.

•

**Radioisotope Surveys** can be made with either of two probes, a beta-gamma discriminating probe or an end-window probe for alpha, hard and soft beta and gamma detection through a portable, battery operated survey meter available from Nucleonic Corp., of America, 196 Degraw St., Brooklyn 31, N. Y.

## Laboratories

**A Research** and development laboratory specializing in application of thermoanalytical research techniques has been established at 12 Brookfield Way, Morristown, N. J. by Saul Gordon and Clement Campbell.

•

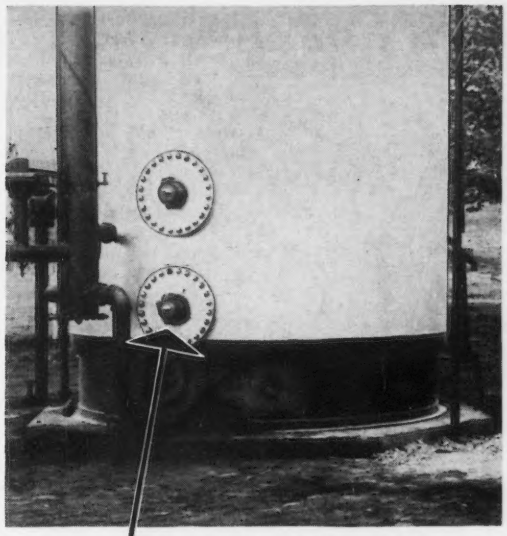
**Tempco Aircraft Corp.** engineering center at Garland, Texas will be expanded by 52,500 square feet on completion of an extension. New capabilities in electronics and missile work will be afforded by the facilities.

•

**Southwestern Laboratories,** P. O. Box 1379, Fort Worth 1, Texas operates units in Houston, Dallas, Beaumont and Midland with a full range of inspection services including radiographic inspection of finished units.

(Continued on Page 96)

# TRICKS... for... TREATERS



Above: 2 of 5 CPS Heater-Treater Anodes installed in a vertical treater.

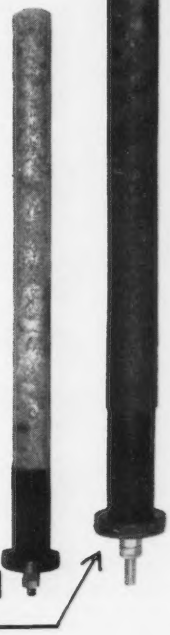
Oilfield emulsion treaters and related equipment . . . handling corrosive brines . . . can well use a few *tricks* . . . to prolong their woefully short life in such service.

CPS has developed, over the past five years, a complete line of cathodic protection materials . . . rectifiers, graphite and magnesium anodes, deck mounts, control boxes, plus other items for use on this specific corrosion problem.

Standard designs have been worked out for the more widely used models of oilfield vessels, in cooperation with the manufacturers.

For complete information, please call or write your nearest CPS office, or consult with your tank company representative.

Vertical mounting fittings for magnesium and graphite suspension.



Right: Heater-Treater magnesium (30") and graphite (60") anodes assembled ready for horizontal mounting. Both lengths available in magnesium or graphite.

*Note:* Caps are now made of plastic.

## cathodic protection service

**P. O. Box 6387** **Houston 6, Texas** **JAckson 2-5171**

Cable Address — CATPROSERV

**Corpus Christi**
**1620 South Brownlee**
**TUlip 3-7264**

**Odessa**
**5425 Andrews Hwy.**
**EMerson 6-6731**

**New Orleans**
**1627 Felicity**
**JAckson 2-7316**

**Denver**
**(Golden) P. O. Box 291**
**CRestview 9-2215**

**Tulsa**
**4407 S. Peoria**
**Riverside 2-7393**

C 5806

# NEW PRODUCTS

(Continued From Page 94)

## Lubricants

**QF-6-7009 Fluid,** an alkyl saline is suggested by Dow Corning Corp., Midland, Mich. as a hydraulic fluid and as a base oil for high temperature turbines at temperatures from —25 F to 550 F for long periods and for short exposures up to 700 F.

## Non-Metals

**Boron Carbide,** a material said by manufacturers, The Carborundum Co., Niagara Falls, N. Y. to have many industrial applications, has a high radiation cross section, is inert to most chemicals, and exhibits good resistance to high temperatures. In sintered body and high density form it can be made in a wide variety of shapes at close tolerances for such applications as blasting nozzles. It is exceeded in hardness by diamonds only.

•

**Soapstone Duct Co.,** 3985 Beach St., Oakland, Cal. is producing Oct-O-Duct, a conduit for underground use said to be far stronger than equivalent concrete and tile sewer culvert or irrigation pipe.

•

**Glasteel 59,** a new glass with 30 percent greater resistance to thermal shock than glasses formerly available and with 20 percent greater resistance to abrasion is now being used industrially by The Pfaudler Co., 1072 West Ave., Rochester, N. Y. It can be used with acids up to 325 F without corrosion damage. It has about twice as much resistance for general alkali service as standard hard-glass laboratory ware.

•

**Linde** synthetic sapphires are being used as balls in a popular make of ball point pen. The sapphires are the hardest material (9 mohs) ever used in a ball point. Linde makes the sapphires in sizes up to 5/8 inch.

•

**On-the-Job** repairs of rubber lined or covered equipment is feasible with a recently developed repair kit available from Automotive Rubber Co., Inc., 12550 Beech Road, Detroit 39, Mich.

•

**Molded Fiber Glass** Company 4401, Benefit Ave., Ashtabula, Ohio manufactures molded fiber glass housings for fluorescent street lights designed by Westinghouse Electric Corp.

## Packaging

**Sleeve-Type Cardboard** cylinders of a type built to government specifications for packing artillery shells are used by Tube Turns, Louisville, Ky., division of Chemetron Corp. to pack all stainless steel and non-ferrous alloy fittings in sizes including 12-inch and all flanges including 8-inch.

## Pipe Line Equipment

**Maloney Model 58** cradles are of full encirclement design. The body consists of two bands of steel, each two inches wide, spaced to an overall width of seven inches. Runners are steel and neoprene. Ribbed rubber linings on bands insulate the pipe and protect the coating. No bolting is necessary. More data are available from F. H. Maloney Co., P. O. Box 1777, Houston 1, Texas.

•

**Midwestern Manufacturing Co.,** Tulsa has introduced a new hydraulically operated sideboom designed for attachment to Case-Terratrac Model 600 industrial crawler tractors with 60-inch tracks. It will handle up to 12-inch pipe and has a maximum lifting capacity of 10,000 lb.

•

**Pipe or Thin Wall** tubing up to 3 inches can be bent accurately at angles up to 180 degrees in a single operation using a portable machine developed by Engineering Associates, 6547 West Blvd., Inglewood, Cal. Maximum distortion to cross section is less than 2 percent. It is powered by either electric or gasoline motors.

## Plants

**Alloy Engineering Co.,** Berea, Ohio has moved into a new 20,000 sq. ft. plant where it fabricates high performance process equipment.

•

**National Cylinder Gas Div.,** Chemtron Corp. is building a $1.75 million liquid oxygen nitrogen and argon plant at Los Angeles.

(Continued on Page 98)

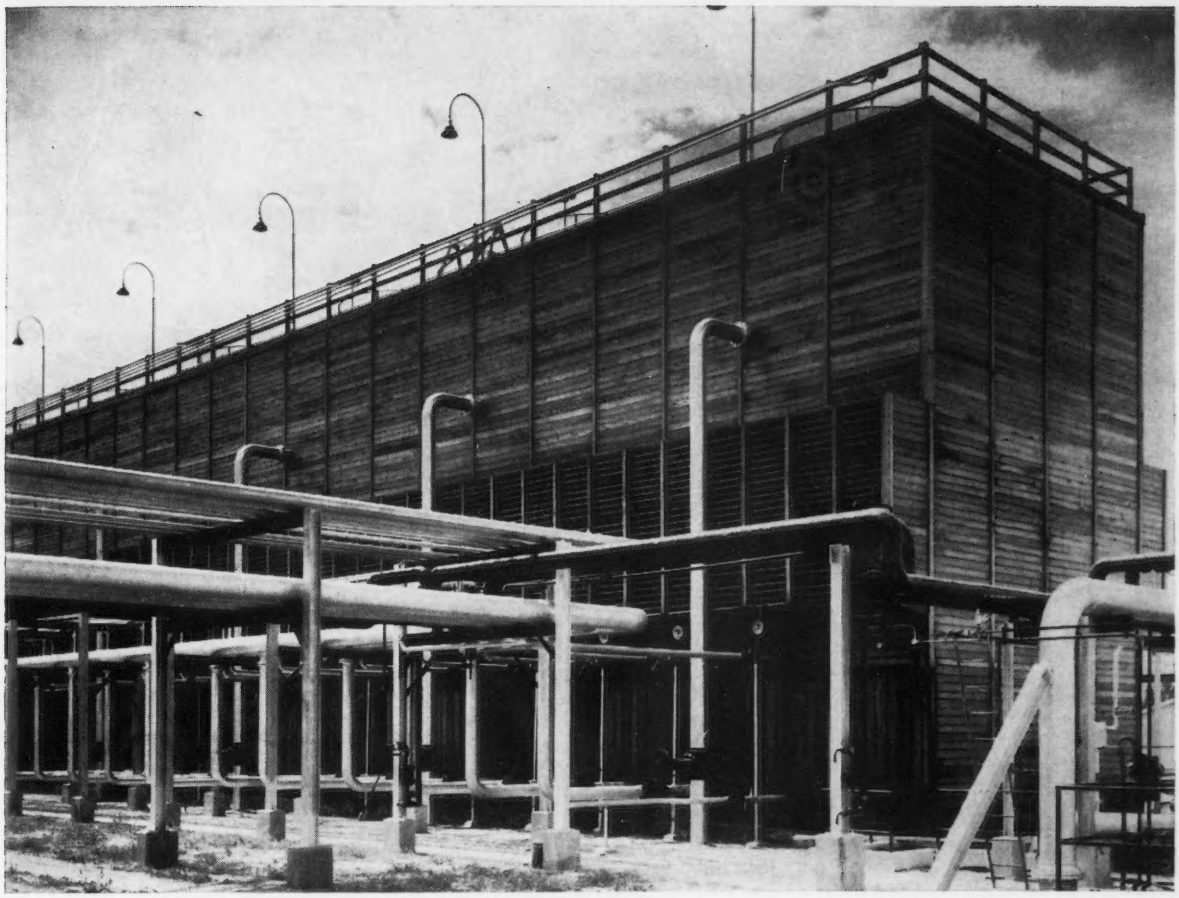
REILLY
NEW 230 X-1
PRIMER

1. Reilly announces a Plasticized Coal Tar Enamel Primer, designed for maximum bond development.
2. Quick-drying (20 minutes± has been reported).
3. Non-sagging and non-curtaining.
4. Great coverage (750 to 1400 square feet per gal.).
5. Stability of bond—no degradation of bond with time and temperature exposure.
6. Derived wholly from coal tar materials, thus fully conforms to A. W. W. A. and governmental agency standards.
7. Gives 100% reliability factor to coating process when properly applied with plasticized coal tar enamel.

*More to come. Reilly 230 X-1 Primer is the first of a series made possible by a significant break-through in applied coal tar surface chemistry. HS X-1 for Reilly Hot Service Enamel and QD X-1 for Reilly Intermediate Enamel will soon be available.*

REILLY TAR & CHEMICAL CORPORATION
1615 MERCHANTS BANK BUILDING
11 So. Meridian Street
INDIANAPOLIS 4, INDIANA

Reilly COAL TAR PRODUCTS
ARMED
Protective Coatings



# CHROMATE COMPOUNDS STOP CORROSION *before it starts!*

Long before the first drop of water contacts metal in any large recirculating water system, steps should be taken to prevent corrosion.

Early in the design stage, plan on adding a chromate inhibiting compound to recirculating water—from the moment operation starts. That way, clean metal stays clean. Chromate inhibiting compounds will also arrest corrosion in older systems that have been operating without protection, even where rust and scale make it more difficult for inhibitors to reach and protect the metal.

Chromates work two ways: they make waters non-corrosive while making metal surfaces corrosion-resistant. Chromate inhibiting compounds are easy and inexpensive to use. Since conditions and equipment vary, a variety of compounds are available to meet individual requirements.

For the names of manufacturers of corrosion inhibiting compounds containing Mutual Chromium Chemicals, or information on Mutual Chromium Chemicals, mail the coupon below.

## Mutual® Chromium Chemicals

Sodium Bichromate
Sodium Chromate
Chromic Acid
Potassium Bichromate
Potassium Chromate
Ammonium Bichromate
Koreon (one-bath chrome tan)

Allied Chemical

**SOLVAY PROCESS DIVISION**
61 Broadway, New York 6, N. Y.

MUTUAL Chromium Chemicals are available through dealers and SOLVAY branch offices located in major centers from coast to coast.

**MUTUAL CHROMIUM CHEMICALS**
**SOLVAY PROCESS DIVISION**
**Allied Chemical Corporation**
**61 Broadway, New York 6, N. Y.**

Please send:

☐ List of manufacturers of corrosion inhibiting compounds.
☐ Booklet "Mutual Chromium Chemicals."

Name_____ Position_____

Company_____

Street_____

City_____ Zone____ State_____

11-10

# NEW PRODUCTS

(Continued From Page 96)

**Good-All Electric Mfg. Company** has opened its fifth manufacturing plant at Ogalalla, Neb.

•

**Electric Steel Foundry** Company's new foundry in Port Coquitlam, B. C. is now producing alloy steel castings from one-half to 5000 lb. in weight.

•

**Oxygen** will be supplied by pipeline from the Erie plant of National Cylinder Gas Div., Chemtron Corp. now under construction on premises leased from Erie Forge and Steel to the latter company. Other industries also will get oxygen, acetylene and other gases, welding supplies and medical equipment.

•

**Aquatrol, Inc.** is now occupying a new plant at 701 Genoa St., South Houston. It suffered a disastrous fire in April 1958. George M. Keith has been named executive vice-president and sales manager and R. O. Johnson, technical service director at Houston; Howard M. Itz is a service engineer for the Houston district and John P. Tognetty, vice-president in charge of production.

•

**Corrosion Services, Inc.** has opened an office and warehouse at 1309 Washington Ave., Cleveland, Ohio. Hartley J. Davis, formerly at Tulsa, has charge of the new office.

## Plastics

**Plastic Casing** for water wells made by Southwestern Plastic Pipe Co., P. O. Box 117 Mineral Wells, Texas is made in nominal sizes 4½, 5½ and 6½ inches, in standard 20-foot lengths. It is true plastic, not fiber, and is jointed with couplings and cement.

•

**Corrosion Resistant** Plastic Equipment available from Haveg Industries, Inc. 900 Greenbank Rd., Wilmington 8, Del. is described in an 8-page illustrated bulletin, C-15.

•

**General Tire and Rubber** Company's Bolta Products Division, Lawrence, Mass. in cooperation with the United Assocaition of Plumbers and Steamfitters and the U. S. Dept. of Labor's Bureau of Apprenticeship and Training recently conducted a 36-hour school for instructors in the properties and fabrication of plastic pipe. Additional courses will be offered.

•

**Teflon, Raylon and Kel-F** products manufactured by Raybestos-Manhattan, Inc., are described in an illustrated Plastic Products Catalog. Copies are available from the company's offices at Manheim, Pa.

•

**Luzerne Hard Rubber** pipe fittings and valves are described in Bulletin PF 1300 available from the company at Trenton, N. J. Diagrams and dimensions are given of threaded fittings, check valves, petcocks, bibcocks and many types of valves.

•

**Type II ABS** plastic pipe is available in four pressure ratings from Southwestern Plastic Pipe Co., Box 117, Mineral Wells, Texas. Numerous new applications for plastic pipe of this type are given in a bulletin available on request.

•

**No. 36-Rigidon,** plastic fans which will handle 27,500 cu. ft. per minute of chemical corrosive fumes are being made by Heil Process Equipment Corp., 12901 Elmwood Ave., Cleveland 11, Ohio. The glass reinforced fans are designed to exhaust corrosive fumes and require no painting on any surface. The company makes fans ranging in size from 6 to 42, those from 36 to 42 being among the largest available in this country.

•

**Fiberglass** reinforced plastic laundry tubs are being made by Structural Fibers, Inc., 5th Ave., Chardon, Ohio. They are made by a process in which glass strands are sucked onto a shape or mold. After curing this preformed shape is transferred to a die mold where resin is applied, followed by pressure. A tub may weigh as little as 7 lb.

•

**Grex** high density polyethylene which is self extinguishing after ignition is made in a number of colors by Polymer Chemicals Div., W. R. Grace & Co., 225 Allwood Rd., Clifton, N. J.

•

**Saran Line Pipe** in standard 8-inch sizes has been added to the group of piping products handled by Saran Lined Pipe Co., Ferndale, Mich. The system includes valves, fittings and pumps for use in the chemical, petroleum, and other industries.

•

**Impal,** a liquid resin said to have a surface tension much lower than capillary resistance of the smallest pores is recommended by Columbia Technical Corp., 61-02 Thirty-First Ave., Woodside 77, N. Y. to seal small cavities in porous metal surfaces. The resultant seal, after curing, resists acids, alkalis and marine atmospheres. Available in several colors, it is compatible with anodized surfaces, and may be coated with any standard coating material.

•

**Plastic Glass Laminate** materials tested by Taylor Fiber Co., Norristown, Pa. transmitted about 25 percent less heat from the surface during five minutes at 2000 F than the most effective homogeneous material tested under the same conditions. Asbestos-phenolic, glass-melamine, glass-phenolic, and nylon phenolic laminates are believed to have uses in space missiles and in industrial applications.

•

**Injection Molded** unplasticized polyvinylchloride fittings and flanges are being made by Tube Turns Plastics, Inc., Box 987, Louisville, Ky. for six-inch piping. The fittings stand 12 times as much pressure as fabricated fittings previously used for these sizes.

•

**Plastic Gas Line** was laid by a Missouri farmer at the rate of 104 feet a minute, using a farm tractor and a home-made device attached to his sub-soiler. He also laid 800 feet of ¾ inch water line. The lines were laid about 20 inches underground, in one day.

•

**QGD-5020** for high impact and QGD-5010 polyvinylchloride plastics for ex-

(Continued on Page 100)

No. 10 PATENTED **BACKFILL**

**FOR MAGNESIUM ANODES**

Moulding Plaster..75%
Wyoming Bentonite .....17.5%
Soda Ash ..... 5%
Lime ..... 2.5%

In 100 lb. moisture-proof bags.
Takes Class C freight rate

Use one of our 14 formulas or we mix to your specifications

**CHARLIE WILSON CO.**

11531 Main St. MOhawk 5-1501
Houston 25, Texas

*Duty*

"Every mission constitutes a pledge of duty"
—Mazzini

It is the accumulation of individual acts, each performed conscientiously, that builds a reputation for reliability.

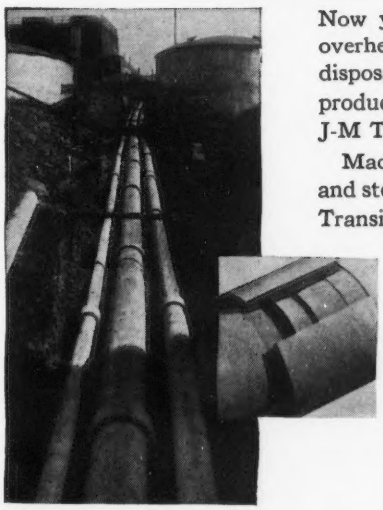
Thus, over the last 28 years, Mayes Bros. has operated under a primary policy which demands that every job, no matter how large or small, be afforded the utmost attention.

Because Mayes Bros. guarantees permanence in pipe coating and wrapping, only the finest workmanship and materials are employed. Mayes' jobs, therefore, stand up consistently under the attacks of underground corrosion forces.

*Why not call on Mayes Bros. for your next pipe coating and wrapping job—and be sure of permanent protection?*

1150 McCarty Drive **MAYES BROS.** Tel. ORchard 2-7566
**HOUSTON, TEXAS**

# Corrosion-resistant TRANSITE PIPE proved best for salt water disposal lines



Transite Pipe is made in a full range of sizes for salt water disposal, lead lines or fresh water supply lines.

Now you can reduce the tremendous overhead involved in replacing salt water disposal lines. Do what more and more producers are doing every year—install J-M Transite® Pressure Pipe.

Made of rugged asbestos and cement, and steam cured for added permanence, Transite is remarkably resistant to the corrosive action of salt water on the inside, soils on the outside. In fact, it has provided years of dependable service in many cases where other pipe materials have failed inside of a few months.

Transite offers many installation economies. It is light in weight and easy to handle. Most sizes can be unloaded and lowered into the trench without mechanical handling equipment. Its Ring-Tite® Coupling speeds assembly . . . provides tight yet flexible joints that permit deflection of pipe without special fittings.

For more information, see your Johns-Manville representative, or write for brochures TR-50A and TR-51A. Johns-Manville, Box 14, New York 16, New York. In Canada, 265 Lakeshore Road East, Port Credit, Ontario.

**JOHNS-MANVILLE**

100 YEARS OF QUALITY PRODUCTS . . . 1858-1958

JOHNS-MANVILLE JM PRODUCTS

# NEW PRODUCTS

(Continued From Page 98)

treme chemical resistance are being made now by Bakelite Company. The materials can be extruded twice as fast as conventional rigid PVC compounds. They were engineered particularly for pipe and contour extrusion applications.

## Process Equipment

**Stainless Steel** liners are used on castered self-dumping hoppers designed for corrosion resistant service by Apex Welding & Fabricating Corp., 30 Interstate St., Bedford, Ohio.

•

**Bellows** machined from aluminum alloys, Inconel-X, A-286 and other high temperature and high strength alloys are available from Hydrodyne Corp., 7350 North Coldwater Canyon, North Hollywood, Cal.


**TECHNICAL REPORTS**

**on**

**CORROSION PROBLEMS in the PROCESS INDUSTRIES**

TP-5A Materials of Construction for Handling Sulfuric Acid. *Corrosion*, August, 1951, issue. $2. Per Copy.

T-5A-3 Corrosion by Acetic Acid—A Report of NACE Task Group T-5A-3 On Corrosion by Acetic Acid. Pub. 57-25, Per Copy $.50.

T-5A-4 A Bibliography on Corrosion by Chlorine. A Report of Technical Unit Committee T-5A on Corrosion in the Chemical Manufacturing Industry. (Compiled by Task Group T-5A-4 on Chlorine.) Pub. 56-2, Per Copy $1.50.

T-5A-5 Corrosion by Nitric Acid. A Progress Report by NACE Task Group T-5A-5 on Nitric Acid. Per Copy $.50.

T-5A-5 Aluminum vs Fuming Nitric Acids. A Report by NACE Task Group T-5A-5 on Corrosion by Nitric Acids. Per Copy $.50.

T-5B High Temperature Corrosion Data. A Compilation by NACE Technical Unit Committee T-5B on High Temperature Corrosion, Pub. 55-6. Per Copy $.50.

T-5C-1 Some Economic Data on Chemical Treatment of Gulf Coast Cooling Waters. A Report of the Recirculating Cooling Water Sub-Committee of NACE Task Group T-5C-1 on Corrosion by Cooling Waters, South Central Region. Per Copy $.50.

T-5C-1 Water Utilization and Treatment Efficiency of Gulf Coast Cooling Towers—A Report of the Recirculating Cooling Water Work Group of NACE Task Group T-5C-1 on Corrosion by Cooling Water (South Central Region) Pub. 57-20, Per Copy $.50.

TP-5C Stress Corrosion Cracking in Alkaline Solutions. Pub. 51-3. Per Copy $.50.

Remittances must accompany all orders for literature the aggregate cost of which is less than $5. Orders of value greater than $5 will be Invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 65c per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

**NATIONAL ASSOCIATION OF CORROSION ENGINEERS**

1061 M & M Bldg. Houston 2, Texas


## Pumps

**Metal-Ceramic LT-1** made by Haynes Stellite Co., 420 Lexington Ave., New York, is used for fabrication of a seal in pumps handling a slurry of alkyl benzene and oleum. The conditions are comparative to those in handling 98 percent sulfuric acid and the slurry is very abrasive. The material, made of chromium oxide, is fabricated by slip casting and is readily machinable. Numerous other applications of the material are described in a bulletin.

•

**Schweitzer Equipment Co.,** 3764 Ridge Road, Cleveland 9, Ohio is making a line of single and double stage diaphragm type pumps to handle corrosive liquids such as acids, alkalis, oils, etc. They also can handle slurries. They range in size from 215 to 35 gpm at 115 psi. Maximum working pressures range from 14 to 230 psi.

•

**Karbate Impervious** graphite centrifugal pumps are being made in three new sizes by National Carbon Company. They are equipped with 1, 1½ and 2 hp 1750 rpm motors. Delivery of the latter two is up to 150 gpm, compared to a top of 80 gpm for previous Type F graphite pumps. The two larger pumps are available with 3 or 5-hp motors for handling fluids of higher specific gravity than water.

## Surface Preparation

**Enth-Acid 82,** a dry, powdered replacement for liquid acids has been introduced by Enthone, Inc., New Haven, Conn. The blend of acid salts, activators and surfactants is effective for activating iron, brass, copper or zinc base die castings before plating and as a pickling agent to remove rust, heat treating scale and weld scale from steel.

## Testing Equipment

**American Research Corp.,** Farmington, Conn. is producing an environmental test chamber measuring 15 x 12 x 25 feet to test completed units or components under a wide range of conditions.

## Valves

**Sapphire** balls are used as poppets in valves made by Whittaker Controls Div., Telecomputing Corp. The sapphires are made by Linde Co. for applications where their extreme hardness is useful.

•

**Stainless Steel** fire cutoff valves made by Cooper Alloy Corp., Hillside, N. J. are held open against two exterior springs by a small fusible link which melts at 160 F. The Type 316 valves are used at American Cyanamid Company's Linden, N. J. Plant to handle cumbustibles at pressures up to 150 psi.

•

Northeast Region's 1958 meeting will be held October 5-8 at Somerset Hotel, Boston.

# MEN in the NEWS

**H. S. Preiser,** Bureau of Ships, U. S. Navy Dept., Washington conferred with representatives of the government of Israel on corrosion prevention methods at sessions from June 10 through 23 at Haifa and Tel Aviv. Over 100 engineers attended meetings at each place. Mr. Preiser also addressed the corrosion group of the Association of Engineers and Architects. He was invited to Israel by the government to confer with engineers in the ministries of defense, transportation, water planning, Zim Israel Navigation Co. and others.

He visited the ports of Jaffa and Tel Aviv and made recommendations concerning the protection shipping, dock and other facilities. He reported to the U. S. Naval attache and will make a full report, which will be made available to the government of Israel.

•

**John C. Hampson** has been named regional manager of the Pittsburg office of Pennsalt Chemicals Corp. Industrial Division. He replaces William P. Snelsire, who retired after 43 years' service.

•

**Vern Frost,** head of Frost Engineering Service Co, 7537 Marbrisa Ave., Los Angeles will handle F. H. Maloney Company pipe line specialty products in Southern California.

•

**Adolph O. Schaefer,** president of Pencoyd Steel and Forge Corp., Philadelphia has accepted appointment to the unexpired term of secretary of the American Society for Metals following the recent death of founder-member William H. Eisenman, who served as national secretary for 40 years. ASM also has appointed a temporary manager, an advisory council and established a new position of secretary to the board.

•

**Walter Welkowitz** has been named director of engineering, Vibro-ceramics division, Gulton Industries, Inc., 212 Durham Ave., Metuchen, N. J.

•

**Robert M. Prochnow** is now sales engineer for Taylor Fibre Co., at its St. Louis office.

•

**Joseph J. Ranna** has been promoted to manager of the New Orleans district sales office of A. M. Lockett & Co., Ltd., sales subsidiary of The Babcock & Wilcox Co.

•

**Vincent P. Mahon,** formerly sales representative in Houston for the Lunkenheimer Co., Cincinnati has been made branch manager at Boston, Mass. He succeeds **Harold T. Wilbur,** who is retiring after 38 years with the company.

•

**Clarence Bremer** has been appointed technical director with responsibility for all research, product development and technical service laboratory work by Oakite Products, Inc., New York, N. Y.

•

**Robert R. Pierce, James H. Cogshall** and **Robert S. Mercer,** NACE members in the Pittsburgh offices of Pennsalt Chemicals Corp. Corrosion Engineering Products Dept. have moved to new Natrona, Pa. offices opened August 4.

(Continued on Page 102)

# 200-hour torture test proves SCOTCHRAP superiority!

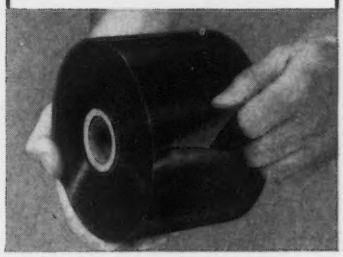
REG. U.S. PAT. OFF
BRAND
PIPE PROTECTION TAPE

Each of these 5 standard pipe lengths was covered with a different commercial pipe "protective" coating—both tapes and mill-coatings. All five pipes were then put in the barrel shown with an abrasive-chip tumbling medium and continuously tumbled for 200 hours. This unretouched photo shows the results: only the pipe coating on the extreme right survived *intact*—the pipe wrapped in "SCOTCHRAP" Brand Pipe Protection Tape. This photo shows clearly and dramatically why "SCOTCHRAP" gives such superior performance in resisting abrasion from backfilling and underground soil stresses. Add to this the superior resistance to electrolytic forces . . . the superior shear adhesion strength . . . and the new low prices, and you have the reasons why we believe "SCOTCHRAP" Pipe Protection Tape is your best total coating buy for entire distribution systems.

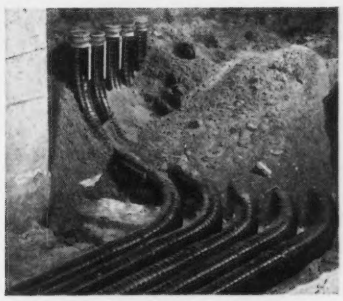
"SCOTCHRAP" is a registered trademark of 3M Co., St Paul 6, Minn.

**"SCOTCHRAP" BRAND Pipe Protection Products**

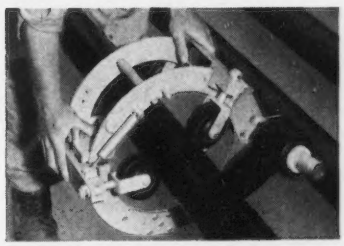
**LOOK what you can do with "SCOTCHRAP"**



**MAKE QUICK,** easy applications to any size pipes. "SCOTCHRAP" is specially formulated polyvinylchloride in handy tape form. It is tough, but conformable; sticks at a touch . . . no heat . . . no mess!



**ACTUAL** field use shows why abrasion-resistance of "SCOTCHRAP" is important: backfill is coarse, rough—could easily puncture or tear less tough coatings.



**SAVE TIME** on total system coverage. With wide-width "SCOTCHRAP" and "Betzel" Tapester, one man covers 200 feet of 4″ pipe in less than 30 minutes.

**INSULATE** joints, tees, elbows in the field. Supercomformable "SCOTCHRAP" does it quickly. For complete information on "SCOTCHRAP", or to arrange demonstration, write: 3M Co., 900 Bush Ave., St. Paul 6, Minn., Dept. BQ-108.

**MINNESOTA MINING AND MANUFACTURING COMPANY**

**. . . WHERE RESEARCH IS THE KEY TO TOMORROW**

3M COMPANY

# MEN in the NEWS

(Continued From Page 100)

**Robert I. Peters** is assistant chief engineer, **R. E. Scheel** is Western sales manager and R. A. Brown, Chicago sales engineer for Heil Process Equipment Corp.

•

**A. R. Murdison** has been transferred to the Winnipeg office of Winnipeg Pipe Line Co., Ltd.

•

**Joseph E. Harkins** and **Bruce E. Dane** have been named territory managers for South Central and Mid-East regions respectively by Alloy Tube Div., Carpenter Steel Co., Union, N. J.

•

**Edgar H. Dix, Jr.,** assistant director of research for Aluminum Company of America since 1942 retired last month. Mr. Dix, in 1954 received the National Association of Corrosion Engineers Frank Newman Speller award for outstanding contributions to the practice of corrosion engineering. He is said to have been directly or indirectly responsible for the development of the majority of aluminum alloys used today, which now number 70.

•

**John D. Leslie** has been appointed assistant district sales manager of the New York district office of Haynes Stellite Co., division of Union Carbide Corp., it was announced recently by R. L. Lerch, vice president of the company.

•

**Schrade F. Radtke,** has been appointed to head the joint research program currently being initiated by worldwide lead and zinc producers. He formerly was a director of the metallurgical research laboratories of Reynolds Metals Co., Richmond, Va. Mr. Radtke has been chosen to manage research projects under the direction of the Industry Development Committees of the American Zinc Institute, Inc. and the Lead Industries Association. He is a member of 15 technical societies and organizations.

•

**George H. Lieser, Roy Romine** and **Lee Stevens** have received appointments to positions with a newly formed division of Wheelabrator Corp., Mishawaka, Ind. The new division was created by the acquisition of the former Crandall Engineering and Manufacturing, Inc., of Vicksburg, Mich. and will be known as the Techline Division. Mr. Lieser who has been department head of the Liquamatte line of wet blast equipment at Wheelabrator, will be field sales manager of the new division; Mr. Romine, who founded Crandall Engineering in 1957 will be chief engineer, and Mr. Stevens will be director of process engineering.

•

**O. E. Isenburg,** general manager of the Harmon Colors division of B. F. Goodrich Chemical Co., has been elected president of the Dry Colors Manufacturer's Association. In addition to his affiliation with DCMA, Mr. Isenburg is a member of the National Paint, Varnish & Lacquer Association and other technical societies.

•

**Grover S. Ramsey** has been assigned as sales representative in Michigan for B. F. Goodrich Chemical Co., it was announced by W. D. Parrish, manager of Hycar nitrile rubber and rubber chemical sales. Mr. Ramsey will make his headquarters in Detroit.

•

**Marvin H. Harrington,** general manager, recently announced that Plastitrol, distributor for Chemtrol plastic ball valves, Vanton Flex-Plug plastic valves and American Plastic Pipe Co. (Carlon), has moved its headquarters to 3118 Firestone Blvd., South Gate, Cal. from Costa Mesa, Cal. Mr. Harrington is a member of NACE.

•

**William Frederick Durand,** aviation pioneer and a past president and honorary member of the American Society of Mechanical Engineers, died August 9 after a brief illness. He was 99 years old. Editor of and contributor to the six-volume definitive work of the principles of gases in motion, "Aerodynamic Theory," his contributions to hydrodynamics and aerodynamics are considered fundamental to the field.

•

**Ralph S. Archibald,** chairman and former president of North Range Mining Co., will be the recipient of the Daniel C. Jackling Award and will give the Jackling Lecture at the annual meeting of the American Institute of Mining, Metallurgical and Petroleum Engineers in San Francisco, February, 1959. The Society of Mining Engineers, a constituent body of AIME announced Mr. Archibald as recipient of the award, given for "significant contributions to technical progress in the fields of mining, geology and geophysics."

•

**Frederick P. Huston** has been named chief methods engineer and **Scott N. Randall** is new chief product engineer of Tube Reducing Corp., Wallington, N. J., it was announced recently.

•

**James N. Pitts, Jr.,** associate professor of Chemistry on the University of California's Riverside campus has been named a consultant to Shell Development Co. Mr. Pitts is considered an authority on photochemistry. He will pursue basic research in the company's radiation laboratory and conduct a seminar on photochemistry for the laboratory staff.

•

**Jerome W. Woomer,** Pittsburgh consultant, will serve as president of the Society of Mining Engineers for one year, beginning February, 1959. The Society of Mining Engineers is a constituent body of the American Institute of Mining, Metallurgical and Petroleum Engineers.

•

**S. S. Moore** has recently associated himself with a new company which markets industrial supplies and equipment. The new firm is S. S. Moore & Associates, 2035 S. W. 58th Ave., Portland, Oregon. Mr. Moore formerly was with General Engineering Sales Co. He is a member of NACE.

•

**Victor K. Nye** has retired from full time duties with the A. M. Byers Company of Pittsburgh. He had been with the company 42 years until his retirement in August.

•

**William P. Henson** and **Milton N. Thompson** have joined the design engineering staff of Mobile Drilling, Inc., Indianapolis. They will be engaged in the design and development of new products.

•

**S. Bruce Humphrey** has been appointed manager of the End Use Research Department of the Carus Chemical Co., Inc., LaSalle, Ill. He formerly was engineering group leader with the U. S. Rubber Co.

**TECHNICAL REPORTS**

**on**

**HIGH PURITY WATER CORROSION**

Symposium on Corrosion by High Purity Water by Committee T-3F on High Purity Water which includes:

Introduction to Symposium on Corrosion by High-Purity Water by John F. Eckel.

Corrosion of Structural Materials in High-Purity Water by A. H. Roebuck, C. R. Breder and S. Greenberg.

Corrosion Engineering Problems in High-Purity Water by D. J. DePaul.

The Importance of High-Purity Water Data to Industrial Applications by W. Z. Friend. Per Copy.....$1.50

Symposium on Corrosion by High Purity Water. Five Contributions to the Work of NACE Technical Committee T-3F on High Purity Water. Pub. 57-22.

Measurement of Corrosion Products in High Temperature, High Pressure Water Systems by A. S. Sugalski and S. I. Williams.

Corrosion of Aluminum-Nickel Type Alloys in High Temperature Aqueous Service by F. H. Krenz.

Corrosion of Aluminum in High Purity Water by R. J. Lobsinger and J. M. Atwood.

The Storage of High Purity Water by Richard R. Diesk.

Water Conditions for High Pressure Boilers by D. E. Voyles and E. C. Fiss. Per Copy.....$1.50

Remittances must accompany all orders for literature the aggregate cost of which is less than $5. Orders of value greater than $5 will be invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 65c per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

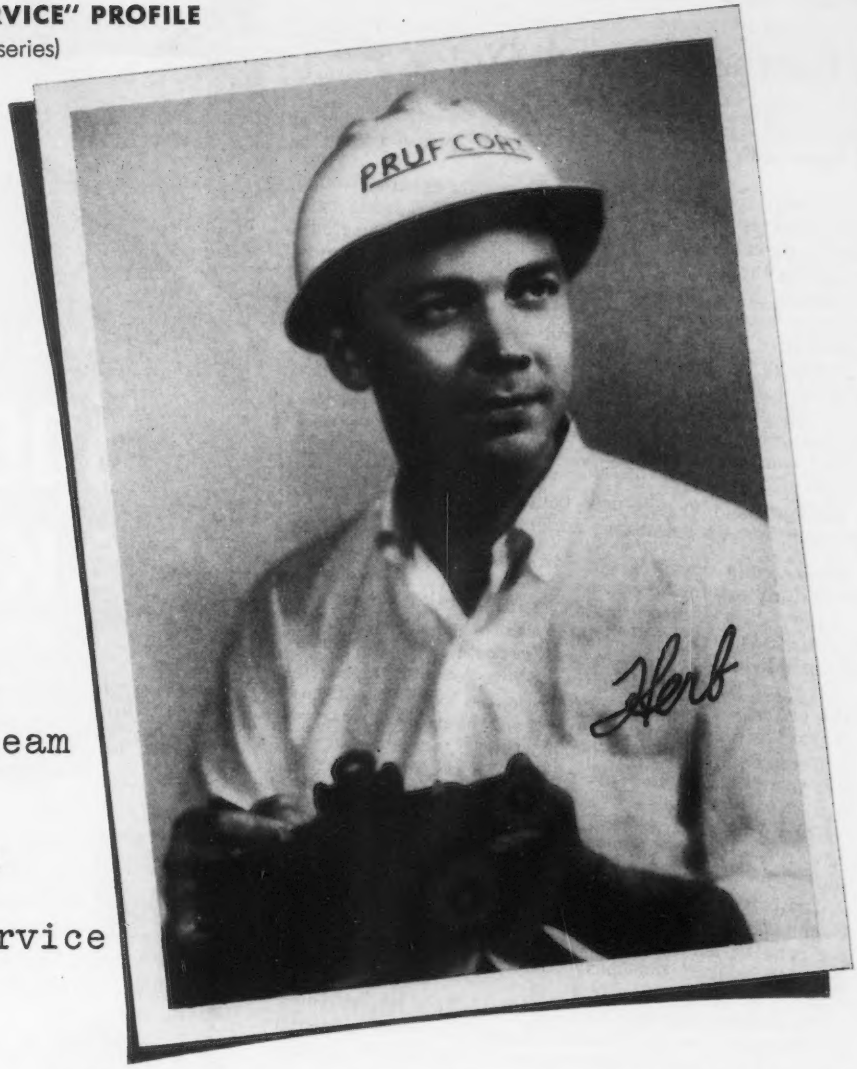
**NATIONAL ASSOCIATION OF CORROSION ENGINEERS**

1061 M & M Bldg. Houston 2, Texas

**NEWS DEADLINE FOR CORROSION**

**News intended for publication in CORROSION should be in Houston not later than the 10th of the month preceding month of publication. When events occur at or near this date, it sometimes is possible to hold space for news stories, provided advance notice is given. An estimate of the amount of space required should be included in the advance notice.**

**A "PRUFCOAT SERVICE" PROFILE**
(one of a series)




Meet
Herb Irish...
a member of
the Prufcoat team
that gives
practical
meaning and
reality to
Prufcoat Service

"Service is *the key* . . . the key to top-dollar performance of corrosion-resistant coatings." That's how Herb Irish sums up his conception of the importance of "service" in the coatings field. And as his customers will tell you, Herb is the kind of fellow who backs up his words with deeds.

After receiving his degree in chemistry from East Tennessee State College in 1951, Herb stayed on at State for a year of special graduate study before going out to make his mark in the chemical world. Then, he wasted no time in putting his college training to good use—in three experience-packed years as technical supervisor in the production, pilot plant, and research and development departments of a major Southern chemical company.

But Herb particularly likes meeting people, likes working with them, likes tackling new problems. So, with a good technical education plus practical plant experience under his belt, he decided on a Prufcoat career of sales *and service* engineering.

In servicing his Gulf Coast territory that stretches from Louisiana to West Florida, Herb is at his most-determined best when temporarily stumped by a protective coating problem. On such occasions there's no rest for Herb—or the headquarters staff that backs him up—until he's convinced he has found the most practical, money-saving answer. And he won't stop there. He will prepare detailed, written recommendations—then help, right on the job itself, to make sure recommendations are followed to the letter. In short, Herb is typical of Prufcoat sales-service representatives everywhere.

PRUFCOAT
PROTECTIVE COATINGS

**WHY NOT PUT PRUFCOAT SERVICE TO WORK FOR YOU?**
*Your* Prufcoat representative can help you plan and execute the kind of corrosion-control program that will save you many precious new construction and maintenance dollars . . . and many maintenance headaches, too! There is no cost or obligation. Just write or call ● ● ●

**PRUFCOAT LABORATORIES, INC., 63 MAIN ST., CAMBRIDGE 42, MASS.**

# In Coatings, Watch Epoxy

**New types of protective materials for prevention of external pipe corrosion—as well as new additions to old types—are vying for the attention of pipeline builders.**

Electrolytic corrosion, caused by currents emitted from pipe metal, is the chief enemy of engineers fighting external pipe corrosion. This corrosion can be counteracted by halting the outflow of electricity. But there's only one way to do that—by enclosing the pipe in a material that will not leave even minute parts of the pipe exposed, regardless of time and soil conditions.

Although the protective coverings developed for pipe to date have many important advantages, no one has come up with the perfect material—the one that will eliminate such corrosion completely. (The "perfect material" would differ according to the conditions of each line.)

Perhaps no one will ever come up with the perfect covering, but manufacturers are trying.

**Epoxy resin coatings are attracting a good deal of interest as external-corrosion preventives.**

Epoxy resin coatings are made from petroleum-derived materials. They're said to combine into one package many of the individual advantages of other coatings.

One industry representative whose job it is to keep tabs on coating developments recently told PETROLEUM WEEK, "Within the next year or two, there will be marked improvement in epoxy resins [coatings], which could enable them to replace some present hot-enamel-type coatings."

Coast Paint & Lacquer Co. came out with one late last year (PW—Dec.20'57,p46). The coating, applied hot, is said to be especially fast-drying.

Coast is one of the 11 associated companies called Copon Associates. The other companies, spread around the country, are now either already marketing, or getting ready to market, the epoxy coating Coast developed last year.

Pittsburgh Coke & Chemical Co., which has marketed a cold-applied similar coating, "Tarset," for other industrial uses for a few years, is now making it available for pipeline application.

Pitt Chem's entry into the field of cold-applied epoxy resin pipeline coatings must certainly be taken as a sign of the times, because the company has for years been marketing a hot enamel coating. Now "Tarset" is moving into direct competition with the older Pitt Chem coating product.

"Tarset," a coal tar epoxy resin which provides protection in a temperature range from —30F to 400F, was recently applied on one system in Venezuela and is now ready for the U. S. market.

Other companies are known to be in experimental stages with similar epoxy type coatings.

BAKELITE BRAND EPOXY

Today, epoxy resins are rapidly growing as the base for protective pipeline coatings. Why? Because they are so easy to apply, efficient in operation, and economical across the board. Epoxy resins bring lower costs in material, time, and maintenance.

For successful coatings both *inside* and *outside* petroleum pipes, BAKELITE Brand Epoxy Resins have been used in a wide range of demanding applications. Now is the time to test them yourself, and learn at first hand how effectively they work.

**BAKELITE COMPANY WILL HELP YOU** find the best coatings for your pipe by providing expert technical assistance. For information and the names of suppliers of coatings made with BAKELITE Brand Epoxy Resins, write Dept. JW-32L, Bakelite Company, Division of Union Carbide Corporation, 30 East 42nd Street, New York 17, N. Y. *In Canada:* Bakelite Company, Division of Union Carbide Canada Limited, Toronto 7.

Protect pipelines with coatings based on **BAKELITE BRAND PLASTICS**

UNION CARBIDE

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## Tests Show

# Most Coatings Blister Under Cathodic Protection*

**Abstract**

Numerous coatings formulations tested under cathodic protection over periods up to 2½ years are considered. Most coating blistered. Blistering is not conclusive evidence of failure, providing base metal exposed does not increase current consumption unduly. Of the materials tested vinyls lost adhesion completely; coal tars blistered but did not sheet off like the vinyls; phenolic or epoxy-modified furanes blistered rapidly as did chlorinated rubber coatings. Neoprene coatings applied over chlorinated rubber primers blistered, but the blisters were small and elastic and adhesion elsewhere was good. Amine cured epoxies formed small blisters quickly; phenolic epoxy amine cured coatings resisted water transmission better but had reduced adhesion and epoxy-polyamid coatings formed blisters smaller than those on the phenolic epoxy types. High water temperatures and high conductivity hasten deterioration markedly.

After blisters formed on epoxy coatings (after 1½ to 2 years) were broken further blister formation was retarded, perhaps because of reduced electrical pressure on the remaining coating.

No data are available on polyurethane, chlorosulfonated polyethylene or other recent formulations because they have not been under test very long. Chlorosulfonated polyethylene formulations using a special liquid catalyst have not blistered in nine months.

THERE are several reasons for using organic coatings with cathodic protection. Cathodic protection provides protection at breaks or flaws in coating films which occur even when the films have excellent resistance to the environment. The cost of cathodic protection can be reduced by a good coating which reduces current consumption and anode attrition.

OH radicals at the cathode area of a cathodically protected surface will produce very strong caustic solutions at the point of formation. pH readings in excess of 12 have been noted in some cases. Atomic hydrogen also produced conceivably can reduce certain resins in coatings and cause their embrittlement and perhaps loss of bond to metal.

Hydrogen attack and caustic and calcareous deposits formed at metal surfaces in water will penetrate any organic film eventually to some degree. The penetration is influenced by a number of conditions which include:

1. Molecular structure of the vehicle of the coating
2. Film thickness
3. Water temperature
4. Pigmentation and grinding processes
5. Physical characteristics of coating film (which can be varied by solvent balance and release)
6. Pressure—hydraulic
7. Pressure—electrical (electrosmosis)

### Effect of Electrical Pressure

When an organic coating film is subject to so-called electrical pressure or potential, the rate of water penetration is accelerated. Also the rate of penetration of the ions is accelerated. As the temperature of the water is increased, penetration is increased. The same is true when water pressures are increased. A practical approach is to actually test various coating formulations in a cathodic protection setup which combines many of the factors previously discussed.

Because the known requirements of a coating intended for use in a cathodic protection system include excellent alkali resistance, water impermeability and good adhesion, coatings without these properties are not considered. For instance, the oleoresinous, some 100 percent phenolics, urea formaldehyde and melamine formaldehyde coatings fail rather rapidly and completely due to poor alkali resistance, so it is pointless to test them.

Following are some of the results obtained from tests made on coatings. Results are of a generalized nature because the program covers five years and it has not been possible to evaluate each coating formulation at all of the varied conditions of different film thicknesses, primer, surface preparations, water temperatures and potentials. Some new coatings have been in test for a year or so only.

### Conditions of Test

Coatings were applied according to recommended procedures as to surface preparation, primers and thickness. Synthetic sea water was used as the electrolyte. Two potential systems for testing the coatings are used:

1. Cell potential is kept constant at 2.2 volts and the cathode-to-ground potential is allowed to vary in accordance with the characteristics of the coating.
2. The coating cathode-to-ground potential is kept constant at 0.95 volts by gradually increasing the cell potentials.

A low initial cathode-to-ground potential is maintained to reduce its destructive (electroosmosis) effect on the coating. Current density was dependent upon number of blisters formed and whether the blisters broke or remained intact. Although some panels had windows and scribed marks, most specimens were coated completely. The completely coated specimens were used to develop coating behavior such as blisters, adhesion, rupture and exposure of bare metal.

### Vinyl Systems

*With Wash Primers*

No blistering was noted, although adhesion was completely destroyed in a comparatively short period. Water penetrated the film and the alkali formed evidently attacked the wash primer and completely destroyed the coating-to-primer adhesion. While no blisters appeared it was possible to cut through the coating and remove the entire film from the panel.

The vinyl film had a good tensile strength and flexibility but very poor elongation before testing. Therefore, when the water and ions penetrated the film and the hydrogen and caustic formed, the film had sufficient strength to prevent cracking but insufficient elongation to relieve itself at any one particular point in the form of blisters. So the water, caustic and hydrogen continued to migrate under the film until the adhesion was destroyed. This points to the destructive effects of strong caustics, which in this case destroyed the presumed phosphoric acid attachment of the vinyl wash primer to the metal surface.

*Without Wash Primers*

Results obtained were very similar to those with the wash primers except that the time required to destroy adhesion was approximately three to five times longer. It was noted, however, that the vinyl film itself had lost much of its original flexibility. This loss of flexibility might indicate attack on the vinyl resins by the hydrogen, which when formed is believed to be in the atomic state. Atomic hydrogen is a good reducing agent and it may well be that vinyl chloride or vinyl acetate resins are chemically attacked.

### Coal Tar Coatings

Coal tar coatings have been used successfully on underground piping systems which are cathodically protected. They are very heavy films and are reinforced with various types of wrapping materials. Also when applied to pipe and reinforced, an envelope effect is produced so no large scale loss of coating due to adhesion failure can occur. Thin films (that is, 15 to 20 mils) of these coal tar pipe enamels will blister on steel sheets when cathodic protection is applied. The blisters are about one inch in diameter and are high, indicating some elongation of the coating. These films will not sheet-off in the way some vinyls do.

### Furane Coatings

Phenolic or epoxy modified furane coatings, will blister rapidly under cathodic protection. Indications are that

(Continued on Page 106)

★ Extracted from a paper titled "Protective Coatings in Use With Cathodic Protection," by F. J. Ploederl, Wisconsin Protective Coatings, Inc., Green Bay, Wis., presented at a meeting of North Central Region, National Association of Corrosion Engineers, Chicago, Ill., October 1-4, 1957.

## Most Coatings Blister—

(Continued From Page 105)

water penetrates these films rapidly because blisters are formed in comparatively short periods. Blisters are small in size and height and are very tough and strong. This toughness is the result of proper modification with the correct epoxy or phenolic. Alkali resistant primers of the epoxy or epoxy-phenolic type do not retard blister formation.

### Chlorinated Rubber Coatings

Large, high blisters form within 25 to 30 weeks on chlorinated coatings. They are tough and resilient.

### Neoprene Coatings with Chlorinated Rubber Primer

Large, high blisters form on Neoprene coatings, if pigmentation and modification are such as to retain the highly elastic properties of the Neoprene vehicle. If the pigmentation is such that the elastic properties are greatly reduced or lost, blisters are moderately small and adhesion at unblistered areas is good. This illustrates the importance of the type and amount of pigmentation as a factor in the behavior of coatings in cathodically protective systems.

### Epoxy Coatings Tests

Due to the large number of modifications of epoxy resins with other resins, their behavior is variable.

*Amine Cured Epoxy Coatings*

Have excellent adhesion but apparently a high water transmission rate. They will transmit current after exposure but because of their adhesion characteristics the blisters formed are small in size and number. They reduce current requirements somewhat but not sufficiently to warrant their use as current reducing barriers in cathodic protection. They are, however, good for use where cathodic protection is added to take care of application flaws.

Their performance is closely related to the amount and type of pigments used.

*Phenolic-Epoxy Amine Cured Coatings*

Have more resistance to water transmission but have reduced adhesion. However, they have better adhesion than other types. Adhesion will vary according to the type of phenolic used for modification and pigmentation. Blister formation varies from very large flat blisters and loss of adhesion over large areas, to very small tough blisters similar to those found in highly pigmented Neoprene coatings.

*Epoxy-Polyamid Coatings*

Behave very much like the phenolic-epoxy type. However, blisters formed are not as large or as high as those found with some phenolic-epoxy amine cured systems.

*Blisters on Epoxy Coating*

It has been observed that first blisters appear on many epoxy coatings after a much longer exposure time than on other coating types tested (1½ to 2 years). It also has been observed that some epoxy coatings will form a few blisters in isolated areas. However, after these blisters are formed or have been broken, further blister formation on the remainder of the coating is retarded or completely stopped. There is no explanation for this except that current density is reduced on the balance of the coating film when current is discharged freely at the areas where the breaks in the coating are located. Therefore, the rest of the coating is functioning under a different set of conditions from that which is protecting breaks in the coating.

### Other Coatings Under Test

Polyurethane, chlorosulfonated polyethylene and other recent developments in coating resins are now under valuation. However, no results are available. Chlorosulfonated polyethylene formulations, using a special liquid catalyst, have not developed blisters or other deterioration after nine months' testing with cathodic protection.

Some tests have been made at elevated temperatures in waters of normal conductivity (Green Bay city tap water). These tests indicate that increased temperature accelerates the rate of blister formation. This acceleration is very great on some coatings. It also has been found that conductivity of the water at room temperature influences the time before blisters are observed. In high conductivity waters blisters appear sooner. This factor also is in the preliminary stage of investigation.

Behavior of coatings under cathodic protection depends upon resin type, pigmentation, flexibility, elongation, adhesion, film thickness, solution temperature and electrical conductivity of the solution and perhaps other factors not yet recognized.

### None Failed to Blister

No coating tested under cathodic protection conditions for as long as 2½ years failed to show blisters or lose adhesion. This does not mean that all coatings failed because apparently, even though a coating may blister this is not serious provided the blisters do not expose too great a percentage of the metal and thereby increase current consumption unduly. If adhesion over a substantial part of the coated area is unaffected, the coating can be called successful.

It appears that a coating which develops small blisters only (although they are in large numbers, but which retain sufficient strength to resist easy mechanical rupture) is best for use when cathodic protection is to be applied.

## Reinforced Plastics Meeting

Reinforced Plastics Div., The Society of the Plastics Industry, Inc. will hold its 14th annual Technical and Management Conference February 3-5 at Edgewater Beach Hotel, Chicago.


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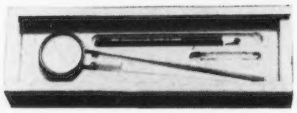
Effective at once the price of single copies of CORROSION to members of the National Association of Corrosion Engineers will be $1 each. The price of single copies to non-members of NACE will be $2 each.

For issues dated two or more years past (i.e. all issues dated 1956 or earlier) the price per copy is $2 to members and non-members alike.


**P B A**



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- Measures inside orifice of sandblasting nozzle in inches.
- Shows air volume required in cubic feet per minute.
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# Improved phenolic linings extend tank life

## *Plastisol gives tank exteriors "lifetime" protection*

Serious tank corrosion often occurs from the outside in. Solution spillage and corrosive atmospheres can deteriorate ordinary coatings and attack the metal, shorten equipment life.

**ELIMINATES MAINTENANCE**

Protecting the exterior of tanks and equipment with Unichrome "Super 5300" Plastisol is good practice, good economy. Especially so where maintenance is difficult. For this same material that is protecting so many tank *interiors* makes *exteriors* corrosion resistant, too. One application usually gives lifetime protection. Non-porous and seamless, this vinyl shield stops corrosive fluids and fumes.

**CAN BE PATCHED**

Its flexibility and toughness help prevent impact and abrasion damage. Should patching ever become necessary, Unichrome "Super 5300" can be sprayed on, spot baked, and protection restored good as ever.

See details in your copy of "CEC", or send for Bulletin Chem C-3.

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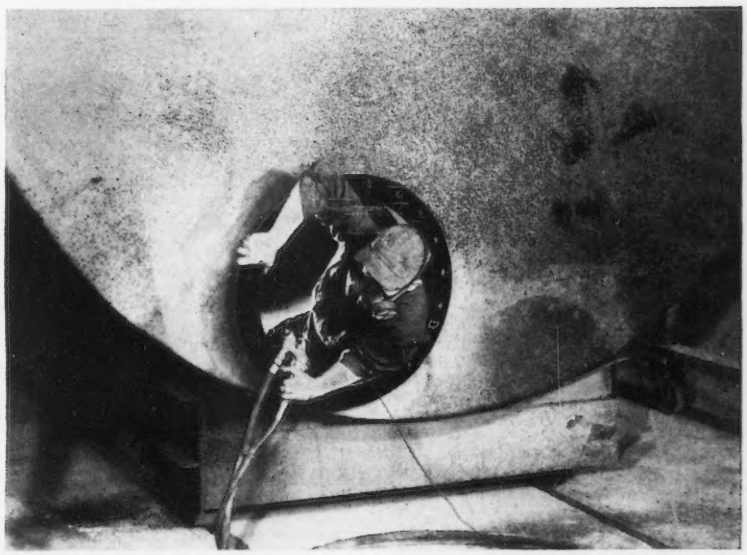


Specialists are located in key areas to apply Unichrome Phenolic Linings. They have the experience and the facilities to handle even large, difficult jobs promptly and properly.
Photo Courtesy General Coating Co., Woodbridge, N.J.

## *Unichrome B-124 Linings have increased resistance to impact, give thicker films, positive cure-control*

Phenolic coatings continue to provide a most economical lining for tanks, tank cars, drums. Features have been incorporated into the Unichrome Series B-124 phenolics that greatly improve the physical properties...increasing their reliability still further for corrosive service.

**WON'T CHIP ON IMPACT**

Improved reverse impact resistance of Unichrome phenolic linings is especially valuable in containers and tanks subject to handling abuses. Linings stick tight, prevent exposure of metal, guard against corrosion and contamination of the product.

**SPECIAL FEATURES**

Unichrome Series B-124 Linings include materials that bake to a hard, glossy surface for an easy-to-clean final coat; others go on as thick as two mils per coat — twice that of ordinary phenolics; still another signals with a visible color change when fully cured, to assure optimum durability.

Unichrome B-124 Coatings stand up in direct contact with wide range of active materials, including strong acids and solvents. Write Metal & Thermit for information and names of nearby applicators that can give you fast service even on large equipment.

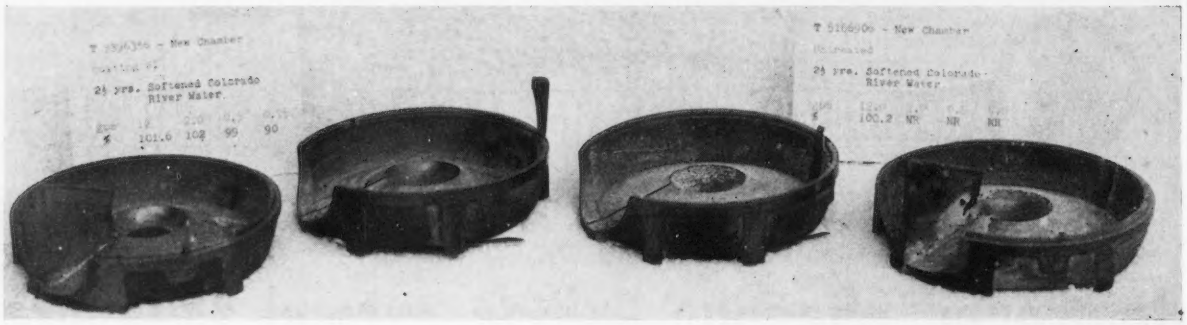



**Figure 1—New measuring chambers. Left, treated with coating No. 1; right, untreated. All chambers in all figures "as is," not washed, wiped or scrubbed.**

# More Revenue from Longer Lasting Water Meters Through Corrosion Control*

WATER METER corrosion has been a serious problem and has cost water works operators millions of dollars since the large scale use of meters started approximately 70 years ago. Because the water meter is literally the "cash register" of the system, the adverse effects of corrosion are two-fold. The direct loss due to deterioration and the resulting cost of repair or replacement are minor compared to the revenue lost due to faulty registration or stoppage. No business can afford to operate with a cash register that is not ringing up the total amount of the sale.

### Experience With Local Well Water

For many years Long Beach was very fortunate because the water supply presented a minimum of corrosion problems, the entire water supply prior to 1942 coming from wells drilled into old gravel beds formed by the San Gabriel River. A peculiarity of the Long Beach ground water supply is that part of it is amber colored and soft and part of it is clear and moderately hard.

It is generally believed that the amber colored portion results when clear San Gabriel River water, ranging in hard ness from 150 to 200 parts per million, percolates through buried peat beds of irregular extent as the Long Beach pumping zone is neared, producing also a naturally softened water. The mechanism probably is a base exchange similar to that which occurs in an ion exchange process, resulting in water as soft as 10-13 parts per million. The water also acquires its amber color and a slight amount of hydrogen sulfide gas. Production of most of the wells was blended, giving an average hardness of 40 parts per million.

When the city was supplied entirely from local wells, a protective coating formed on the interiors of the bronze meter chambers. This deposit had no adverse effect on registration and was removed very easily by scrubbing with a bristle brush under flowing water. Almost all meters brought in for nonregistration contained sand or other foreign matter, or discs broken or warped by hot water.

Meter parts were replaced because of wear far more frequently than because of corrosion. Bronze measuring chambers, after 20 or more years' exposure, were in such good condition that the only attention needed was to wash with water and polish lightly with crocus cloth.

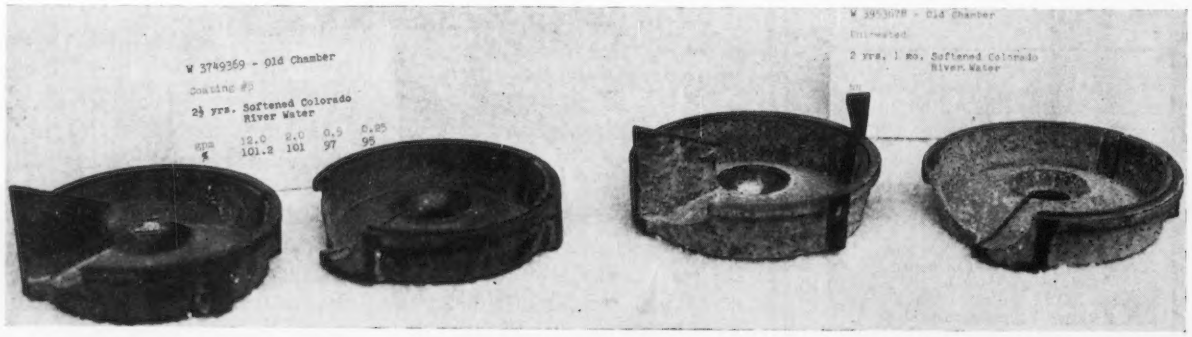
Cast iron case compound meters did not present any serious corrosion problems because very few tubercles formed, so many were left in service for as long as 15-20 years. Meters tested when returned to the meter shop were found to be operating very satisfactorily. Interiors of the cast iron cases were cleaned by scrubbing and meters were replaced in the field with no further treatment.

### Softened Colorado River Water

In the spring of 1942, Long Beach began serving the portion of the city west of the Los Angeles River Flood Control Channel with softened Colorado River water. The character of this water was so different from that formerly supplied that shortly afterwards many meters stopped. These were found to have a soft white deposit of zinc carbonate which would stop the meter when an accumulation formed in the measuring chamber. An examination of meter parts indicated the deposits came

* A paper presented under the title "Corrosion Control for Water Meters," by Harold E. Wilson, Distribution Division Engineer, Long Beach Water Department, Long Beach, Cal., at a meeting of Western Region, National Association of Corrosion Engineers, San Diego, Cal., October 23-25, 1957.

**Figure 2—Old measuring chambers. Left, treated with coating No. 2; right untreated.**



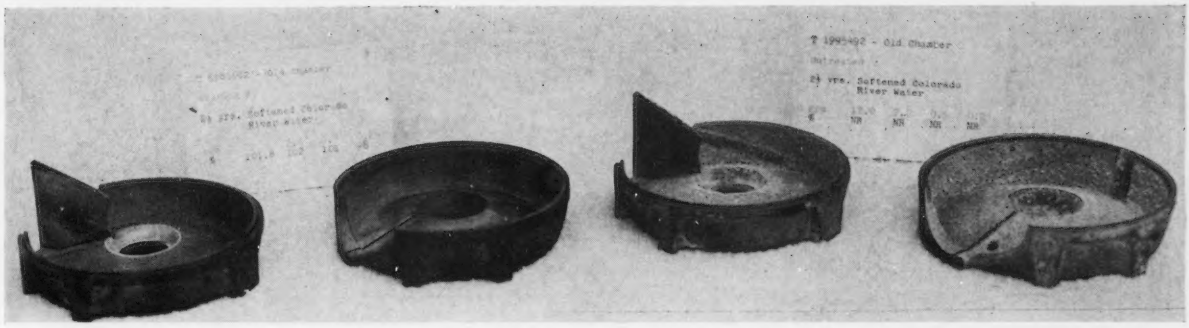


Figure 3—Old measuring chambers. Left, treated with coating No. 5; right, untreated.


## Abstract

Experience of the Long Beach Water Department is related in the attack by softened water and blended water on domestic and commercial water meters. After softened Colorado River water was turned into mains in 1942 and subsequently in 1951 after opening of the water treatment plant, various difficulties were encountered with meters. These included plugging and galvanic corrosion damage which affected the meters' operation and accuracy.

Corrective measures included replacing dissimilar metal parts in meters wherever possible and coating interiors and parts with a low viscosity oil base coating which contained a series of inhibitors. Results of this program have proved a satisfactory answer to corrosion problems. Plastic paint is applied to interiors and parth of cast iron case compound meters which have dissimilar metal parts.

Saving from corrective measures in improved meter accuracy and performance are estimated to be greater than the savings in meter parts and repair expense. An increase of one percent in average registration of meters is estimated to mean an added $24,657 revenue in one year. A two percent increase in registration will bring sufficient revenue to more than pay for the cost of protecting the meters. Replacement cost of 68,260 meters in the system is estimated to be $2,539,492. 7.2


from zinc anti-corrosion rings* or yellow brass sand rings. Substitution of copper or rubber sand rings eliminated these difficulties.

Sodium hexametaphosphate was added to the system to delay or inhibit the after-precipitation of calcium carbonate in the zeolite softened water and to cause the gradual coating of the outlying parts of the distribution system, reducing accumulations near the source of supply. It also was believed that the phosphate not only would prevent excessive deposition, but also would inhibit corrosion because of its power to form a thin protective film on the surface of metal with waters having pH values of 8.4-8.5. During the transition period from the old deposits to the new, phosphates were added at three parts per million and then discontinued as the system became stable.

After several years' exposure to softened Colorado River water, meters were brought in with bronze measuring chambers coated with a hard blue-green deposit, which was difficult to remove except in an acid bath. The deposit was found to be much greater on new meters and on reconditioned meters with uncoated chambers installed after the use of Colorado River water was started. Meters which had been exposed to well water were protected to a large degree by the coating deposited by the well water. Trouble encountered with meters with open gear trains, due largely to dezincification was corrected by converting to oil-enclosed gear trains. Galvanic corrosion resulting from coupling dissimilar metals was the most widespread and persistent type of corrosion encountered.

The contrast between the corrosion effects of Long Beach well water and softened Colorado River water is very strikingly presented in an article[1] by Lee Streicher on the effects of water quality on various metals. This article also compares these waters to Long Beach well water treated to remove color and odor.

* Installed by some manufacturers to give galvanic protection to bronze measuring chambers as a substitute for the copper sand ring. The cast zinc ring, with heavy triangular-shaped projections on the outside to give a relatively large area and volume of zinc, acted as a sacrificial anode. In corrosive waters they were of no benefit because they were completely deteriorated in a few months and the zinc corrosion deposit, in many cases, stopped the meters.

### Treated Well Water and Softened Colorado River Water

The Long Beach Water Treatment Plant was placed in operation on June 27, 1951. The treatment process, briefly, consists of: Aeration to release the hydrogen sulfide; addition of 12 ppm chlorine with 12-hour retention in the pre-treatment basin; addition of 14 ppm lime to adjust the pH; addition of ¼ ppm activated carbon followed by filtration; and post chlorination to obtain a residual of 0.85 ppm as it enters the system.

A blend of treated water with 5-20 percent softened Colorado River water now supplies all of the city with the exception of the Harbor District and North Long Beach. Many difficulties were encountered when this blended water was first introduced. These difficulties, while similar to, were of lesser magnitude than those experienced upon introduction of Colorado River water on the west side. They largely resulted from the effects of deposits developed over long periods dropping off after the sudden change of water quality. There were many complaints of "red" water and many non-registering meters. After a few months new deposits compatible with the new environment developed in the system and the unstable conditions passed. This blended water was found to be much more corrosive than the well water but not nearly as severe as the softened Colorado River water. Table 1 presents the comparative analyses of well water, blended water and softened Colorado River water.

### Attempts to Minimize Corrosion

As corrosion problems increased in magnitude following the change to Col-

(Continued on Page 110)

Figure 4—Old measuring chambers. Left, treated with coating No. 3; right, treated with coating No. 4.

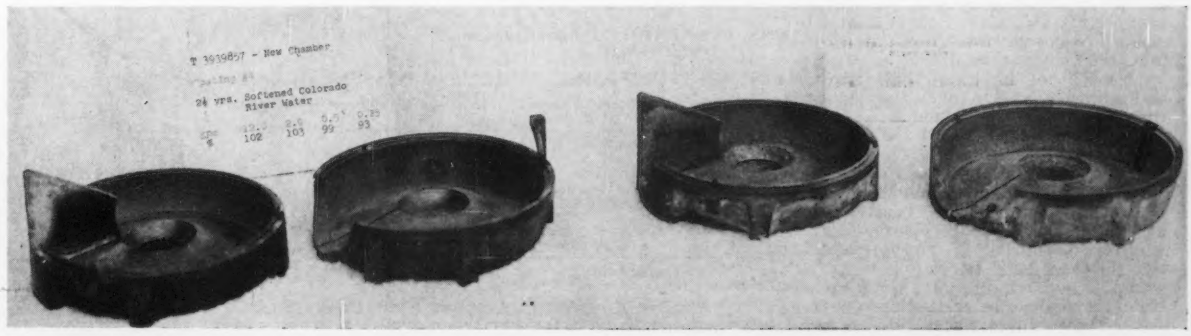


**Figure 5—Old measuring chambers. Two left, coated with No. 6; center two, with No. 8. Two at right, new measuring chambers coated with No. 7.**

## More Revenue—

(Continued From Page 109)

orado River water, all galvanic couples were eliminated wherever possible through use of similar metals. Small parts which could not be made of cast bronze (85 copper, 5 tin, 5 zinc and 5 lead) were made of Monel or phosphor bronze, which are cathodic to, and therefore protected by, the large areas of 85-5-5-5 bronze. While these practices helped, it became very apparent that meters reconditioned and replaced in the field with clean, uncoated bronze measuring chambers were subjected to a very severe attack. Failure often occurred within one or two years. Used chambers, cleaned with inhibited hydrochloric acid, neutralized and thoroughly rinsed, were subject to especially severe attack. Meters examined after a few months' exposure were found to have a heavy blue-green deposit consisting of approximately 30 percent copper sulfate, 60 percent copper carbonate and approximately 2 percent zinc carbonate. This deposit built up on the inside walls of the measuring chamber and in the ball socket until the friction on the disc became excessive. The meter failed to register accurately or stopped completely. This deposit occurred with equal frequence among several makes of meters. Irregularly-shaped pits were found under these localized deposits. When the meters were thoroughly cleaned and replaced in service, corrosion recurred at an accelerated rate in these pits.

### Field Corrosion Studies

Early in 1955, the condition of meters exchanged in the North Long Beach area served by softened Colorado River water, indicated that some protective coating should be applied, because elimination of galvanic couples was not sufficient. Having tried tin-plated chambers in the past, with varying degrees of success due to failures of the plated surface, it was thought that a grease or oil-type coating offered the greatest promise. It was also thought that laboratory corrosion tests using water samples were not conclusive, as it was impossible to duplicate the corrosive and abrasive effects of water flowing through meters in the field.

Therefore, in April 1955, 300 pairs of meters were placed in the North Long Beach area where the most severe corrosion had been experiencd. Bronze measuring chambers were coated with several types of highly regarded corrosion-resistant coatings. Approximately two-thirds of the meters in each test group contained old measuring chambers cleaned with acid. Each of the treated meters was placed with an identical meter containing an untreated measuring chamber adjacent to it as a control. The following coatings were selected for testing:

**Coating One**—Microcrystalline wax and long fiber petrolatum, reduced by 15 percent naphtha containing a series of inhibitors, non-drying with non-toxic ingredients.

**Coating 2**—Low viscosity oil base with high film strength, containing same series of inhibitors as in coating one.

**Coating 3**—Corrosion resistant grease containg zinc oxide.

**Coating 4**—Rust-preventive oil of extremely low viscosity, polar compound water-dispersing oil.

**Coating 5**—Heavy body oil containing no toxic ingredients, good water-dispersing oil.

**Coating 6**—Compostion unknown.

**Coating 7**—Pure phenolic resin dispersed in alcoholic solvents, chemical and abrasion resistant.

**Coating 8**—Clear lacquer.

It was realized that while the list did not include all available corrosion-resistant coatings it was thought the ones selected were representative.

The meters were tested and found to conform to the recommended standards for repaired meters. All repaired meters registered 90 or more at the minimum test rate of 0.25 gpm. The average of the test meters was 99.8 at 12 gpm, 101.8 at 2.0 gpm, and 93 at 0.25 gpm.

Treated meters and their untreated controls were removed for testing and inspection at 6-month intervals, after one year's initial exposure. Results are condensed in Table 2, which presents the average for each type of coating of all the meters examined. Effectiveness of the treatments is reflected in the order in which they are shown in the table. However, this is a continuing study and results are not conclusive.

Approximately one-fourth of the test meters have been examined and the remaining meters will continue to be checked at 6-month intervals. So far there have been no failures because of corrosion. Three treated meters were non-registering at the 0.25 gpm rate. These were excluded from the tabulation because it was apparent that the disc had been fitted too tightly and the faulty registration was caused when the discs began rubbing after a slight swelling. In all treated meters the chambers were in excellent condition with no evidence of corrosion or deposit. In contrast, the following were observed on 72 untreated meters:

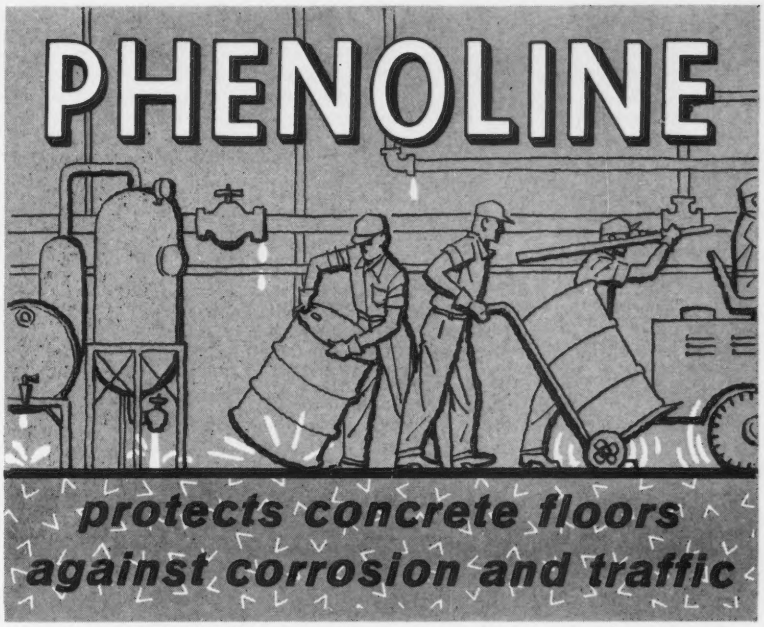
55 non-registering at 0.25 gpm
39 non-registering at 2.0 gpm
29 non-registering at 12.0 gpm and,
26 removed as non-registering at all flows.

Accuracy of the treated meters has far exceeded expectations. Coatings which showed no indication that corrosion deposits were starting to form after

(Continued on Page 112)

**TABLE 1—Analyses of Long Beach Water Supplies**
**Averages for Fiscal Year Ending June 30, 1957**

| Constituents | Well Water ppm | Blended Water ppm | Softened River Water ppm |
|---|---|---|---|
| Silica (Si) | 16 | 14 | 10 |
| Iron (Fe) | Tr | Tr | Tr |
| Calcium (Ca) | 18.0 | 25.7 | 36 |
| Magnesium (Mg) | 1.9 | 4.5 | 14 |
| Sodium (Na) | 60 | 99 | 225 |
| Potassium (K) | 1 | 2 | 5 |
| Carbonate ($CO_3$) | 1 | 2 | 4 |
| Bicarbonate ($HCO_3$) | 179 | 160 | 126 |
| Sulphate ($SO_4$) | 11 | 100 | 364 |
| Chloride (Cl) | 19 | 50 | 114 |
| Boron (B) | 0.2 | 0.2 | 0.16 |
| Fluoride (F) | 0.3 | 0.3 | 0.4 |
| Total Dissolved Solids | 217 | 377 | 836 |
| Hardness (As $CaCO_3$): | | | |
| Total | 53 | 84 | 148 |
| Carbonate | 53 | 84 | 109 |
| Noncarbonate | 0 | 0 | 39 |
| Alkalinity: | | | |
| Phenolphthalein | 1 | 2 | 3 |
| Methyl Orange | 147 | 140 | 109 |
| Color | 37 | 6 | 4 |
| Specific Resistance (ohms/$cm^3$) | 3110 | 1840 | 749 |
| Hydrogen Ion Concentration (pH) | 8.4 | 8.4 | 8.5 |
| Free Carbon Dioxide $CO_2$ | 0 | 0 | 0 |

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Top coat—Phenoline 300
**Total Thickness** (trowel): ⅛ inch

**2** ***SEVERE CORROSION • LIGHT TRAFFIC***

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**SYSTEM:** Prime coat—Phenoline 300 Orange
Intermediate coat—Phenoline 302
Top coat—Phenoline 300
**Total Thickness** (brush or spray): 1/32 inch

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# 86 Percent of Revenue Comes From Small Meters

(Continued From Page 110)

two and one-half years' exposure exhibit every sign they will give protection for ten years.

### Loss of Revenue Due to Corrosion

Table 3 shows the revenue from the sale of metered water in the City of Long Beach during the fiscal year 1956-57. It does not include the monthly service charge paid by each customer regardless of the amount of water used. Importance of the benefits derived from treating bronze measuring chambers is evident when it is realized that 86.3 percent of water sales for $2,465,718 is through ¾ to 2-inch services, metered with bronze disc meters. Each increase of one percent in the average registration of these meters would have increased revenue $24,657 for the past fiscal year.

Considering this, it is apparent that the true cost of corrosion in water meters is much greater than the loss due to depreciation or destruction of expensive meter parts. Approximately $55,000 worth of repair parts were used in repairing 9722 meters last year. An overall increase of two percent in the average registration of meters of all sizes in system would have exceeded the cost of the parts used.

### Current Corrosion Prevention Practice

Because the Long Beach Water Department has 68,260 meters, representing a total investment of $1,246,220 (with a current replacement cost of $2,539,492) it was necessary to start an immediate corrosion control program. A treatment program was started similar to that used by several other cities in Southern California, including Lompoc, Oceanside, Newport Beach and Ventura, which long have been dealing with highly corrosive waters.

At Long Beach the measuring chambers still are cleaned with an inhibited hydrochloric acid, then neutralized and thoroughly rinsed. Deposits are so hard it is thought that removal with a wire buffer would result in more damage to the chamber than is caused by acid etching. It is considered essential to remove all of the corrosion deposit in the pits if adequate adhesion of the oil film is to be obtained. The ball socket is buffed and the disc ball is lapped in, using a fine grinding compound. After the disc has been fitted to the chamber, the chambers are heated for fifteen minutes at a temperature of 250 F to remove moisture. The chambers are then placed in metal baskets and immersed for approximately ten minutes in a bath of Coating 2 heated to 160 F in a thermostatically controlled oven. The oil is allowed to drain and the excess is wiped from the interior. At the start of this program a group of meters was carefully tested before and after treatment to check the effect of the oil coating on their accuracy at low flow rates and there was no evidence of any adverse effect.

In January 1956 the Coating 2 treatment was extended to include nickel bronze measuring chambers used as replacements for deteriorated bronze chambers. The nickel bronze used is standard bronze with 20 to 22% nickel added. As shown in Table 2, these chambers do not have sufficient corrosion resistance to Colorado River water to permit their use uncoated.

Although nickel bronze is slightly cathodic to standard bronze, the solution potential and current flow is not adequate to protect the chamber at the expense of the bronze casing. So fare a conclusion has not been reached as to whether the increased cost of these chambers is offset by improved resistance to corrosion when both types of bronze chambers are coated. This can be determined only by a careful analysis of field experience after both types have been exposed for longer periods.

A total of 19,000 meters has been treated with Coating 2 since this treatment was started in August 1955. Cost of treating ¾-inch meters is less than 20 cents per meter. The program was expanded further in July, 1956 to include new meters purchased with nickel bronze or tinned measuring chambers. A total of 650 new meters has been disassembled, treated and reassembled at a cost of approximately 40 cents per meter.

### Cast Iron Case Compound Meters

Long Beach has a large number of compound meters with cast iron cases and bronze interior fittings and measuring chambers. The bronze-to-cast iron couple produces the greatest galvanic potential and current flow of any galvanic couple encountered in water meters. One large meter manufacturer galvanizes the iron cases of its iron case compound meters. This causes a still higher galvanic potential and current flow for a short period, during which time the zinc coating is rapidly removed to expose the iron surface, restoring the action to primarily an iron-bronze couple. Experience at Long Beach has been that galvanizing the interior of the iron cases causes additional problems because zinc carbonate and sulfate deposited in and around the measuring chambers has an adverse effect on registration.

### Cement Lining Is Tried

An attempt is made to combat deterioration of iron case meters by applying a protective coating to the iron surfaces. Several materials were tried, including cement lining the entire meter case which, incidentally, was found to be much more successful than antici-

(Continued on Page 114)

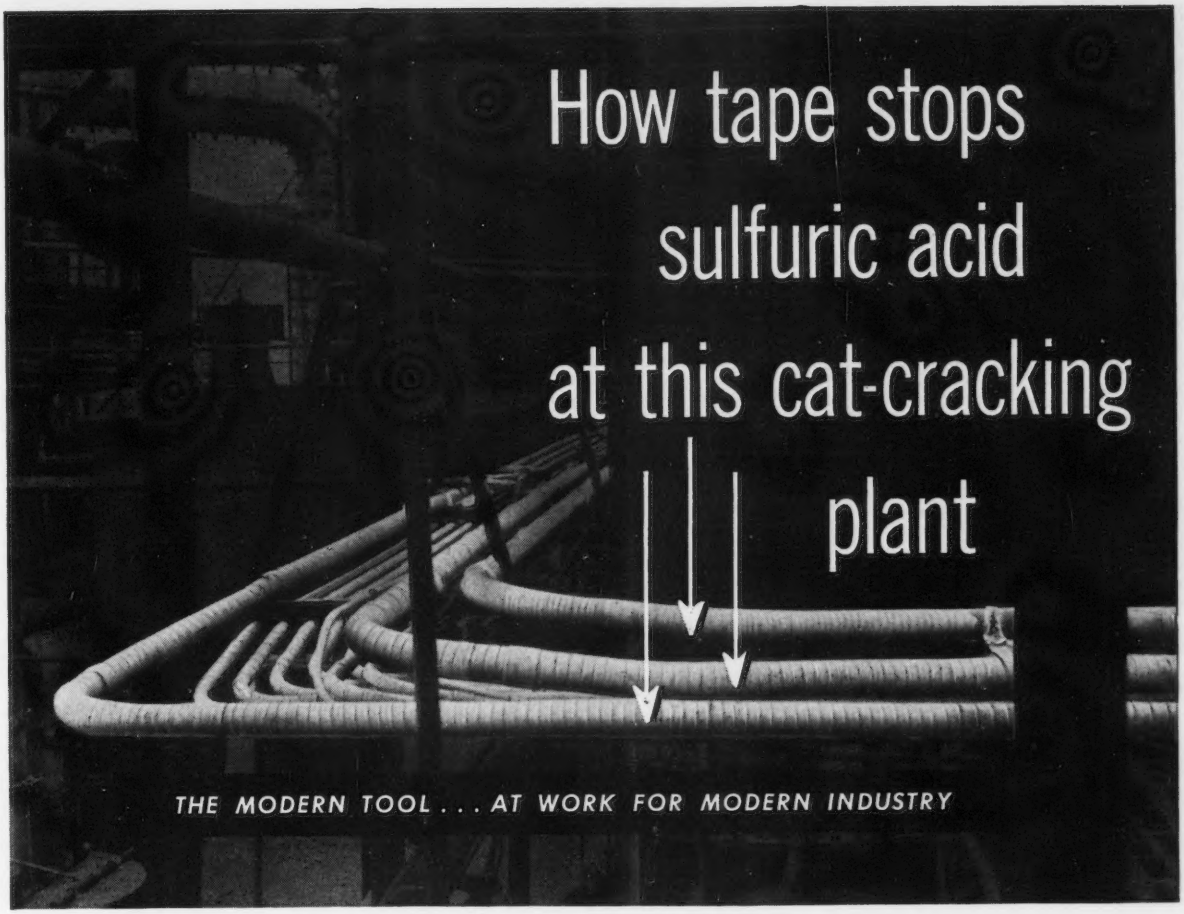
**TABLE 2—Tabulation of ¾-Inch Test Meters**

| Coating Number | No. Tested | Average Registration in Percent 12.0 gpm | 2.0 gpm | 0.5 gpm | 0.25 gpm | Condition of Chamber |
|---|---|---|---|---|---|---|
| **TREATED STANDARD BRONZE MEASURING CHAMBERS** | | | | | | |
| 1 | 13 | 101.8 | 103 | 100.2 | 91.7 | Excellent, no deposit. |
| 2 | 12 | 102.0 | 103 | 99.9 | 93.0 | Excellent, no deposit. |
| 3 | 12 | 102.2 | 102.7 | 100.0 | 95.3 | Excellent, no deposit. |
| 4 | 6 | 101.4 | 103.2 | 97.7 | 92.2 | Excellent, light green-white deposit. |
| 5 | 6 | 101.4 | 103.3 | 97.0 | 88.5 | Good, light green coating, few pits starting. |
| 6 | 5 | 101.8 | 103.2 | 99.3 | 91.8 | Good, light green coating. |
| 7 | 1 | 99 | 102 | ..... | 90 | Excellent, surface scratches, no deposit. |
| 8 | 7 | 103.2 | 104 | 100.5 | 92.9 | Good, small blisters, pits forming. |
| Average of Treated | 62 | 102.0 | 103.1 | 99.5 | 92.5 | |
| **Types of Meters and Treatment—Untreated Standard Bronze Measuring Chambers** | | | | | | |
| Meter A | 52 | 59.9 | 40.9 | 33.6 | 18.8 | Hard blue-green deposit, badly pitted. |
| Meter B | 20 | 61.3 | 54.7 | 26.7 | 26.2 | Hard blue-green deposit, badly pitted. |
| Average of Untreated | 72 | 60.3 | 44.7 | 31.2 | 20.9 | |
| **Nickel Bronze Chambers** | | | | | | |
| Untreated | 10 | 101.2 | 83.8 | 65 | 51.3 | Fair. |
| Treated (Coating 2) | 4 | 101.2 | 105 | 99 | 91 | Excellent. No deposit. |

**TABLE 3—Water Sales 1956-1957***

| SIZE (Inches) | No. of Services | 1000 Cu. Ft. | Percent of Water Sold | Water Sales | Percent of Sales |
|---|---|---|---|---|---|
| ¾ | 56,888 | 971,202 | 56.8 | $1,843,510 | 64.5 |
| 1 | 6,127 | 182,750 | 10.7 | 342,776 | 12.0 |
| 1½ | 1,211 | 77,124 | 4.5 | 137,315 | 4.8 |
| 2 | 848 | 90,814 | 5.3 | 142,117 | 5.0 |
| 3 | 121 | 58,323 | 3.4 | 73,576 | 2.6 |
| 4 | 65 | 60,125 | 3.5 | 71,107 | 2.5 |
| 6 | 29 | 78,189 | 4.6 | 78,071 | 2.7 |
| 8 | 12 | 44,144 | 2.6 | 46,947 | 1.6 |
| 10 | 8 | 25,050 | 1.5 | 21,484 | 0.8 |
| 12 | 5 | 62,647 | 3.7 | 52,330 | 1.8 |
| 16 | 1 | 58,006 | 3.4 | 47,243 | 1.7 |
| Total | 65,315 | 1,708,374 | 100.0 | $2,856,476 | 100.0 |

* Water used by non-paying city departments not shown.

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(Continued From Page 112)

pated. A 4-inch compound meter removed after four years' exposure to softened Colorado River water was found to have very little deterioration of the cement lining and only a very small amount of lining spalled off near the inlet and outlet ports. However, experience with other coatings was sufficiently better that the cement lining was removed by sandblasting and a plastic paint applied.

Current practice, based on approximately five years of field experience, is as follows:

The meter is completely disassembled and as many bronze parts and fittings are removed as possible. Seat rings and bushings left in place are covered with masking tape. All sharp edges are carefully ground off with special care being given to the inlets and outlets. This eliminates one of the weakest points in any paint type coating. The interior of the iron case then is thoroughly cleaned by sand-blasting with silica sand. Old pitted meters are thoroughly cleaned to bright, sound metal, with no rust spots showing. On new galvanized iron case meters the galvanizing is completely removed by sandblasting to provide better bond for the plastic paint. The first coat of paint is applied shortly after the blasting is completed, because the case iron will become covered with a light coat of rust if left overnight for more than a few hours. A sea coast location is a severe environment.

Plastic paint is applied with a brush, because this produces a much more uniform coverage than can be obtained with a spray gun, due to limited accessibility of points in the interior of the case. Contrasting colors are used to assure complete coverage on each coat.

Originally two coats were used. The first black coat was allowed to cure for 24 hours, before a second light grey coat was applied. Approximately three to four days is allowed for the coating to cure before assembling the meters. The painted surface is extended over the edges of the bronze parts left in the case and over the front of the flanges to give a continuous unbroken surface. Irregularities or high spots on the flange surface are removed by draw filing after the coating is thoroughly dry.

Recently a third coat was added because some meters removed were found with tubercles formed due to pinholes in the paint surface. Three thin coats; grey, black and then grey has lessened the possibility of this occurring.

Bronze parts are treated by preheating in an oven at a temperature of 250 F for approximately 15 minutes and then by immersion for approximately 10 minutes in a bath of Coating 2 heated to 160 to 170 F. After all bronze parts have been installed the interior of the meter is given a covering of Coating 2. This is applied as a further precaution against pinholes.

The plastic paint used, a catalyst-cured modified epoxy resin, has shown no signs of deterioration in five years of service.

### Bronze Case Compound Meters

Compound meters, with the main case cast of the same bronze alloy used in the bronze measuring chambers and interior fittings, are found to require much less protection. This is a bronze with approximately 85% copper, 5% zinc, 5% tin and 5% lead. Galvanic corrosion has been reduced to a minimum by making small parts, such as measuring chamber diaphragms, spindles and screws of phosphorus bronze or Monel, which are cathodic to the bronze so any galvanic couple resulting tends to protect the small parts at the expense of the heavy bronze parts. Although this type construction does reduce the effect of galvanic corrosion they require further treatment, nevertheless.

The meters are disassembled. The bronze interior parts and measuring chambers are removed, preheated and immersed in a heated solution of Coating 2 in a manner similar to that described for iron case compound meters. The bronze case is heated to approximately 200 F using an acetylene heating torch on the outside of the case to remove moisture. This has to be done very carefully to avoid damaging the case by overheating. The entire interior is then covered with hot Coating 2 applied with a paint brush. The hard rubber disc piston or turbine wheels are given a thin coating with the coating by wiping with a saturated cloth. The meter is then reassembled and tested. Careful testing before and after this treatment has revealed that there is no significant change in registration.

### Conclusions

Experience at Long Beach indicates that the cost of galvanic corrosion damage to meters is not the most serious loss. Loss of revenue from faulty registration and stopped meter exceeds the cost of repairs and replacement. Elimination of dissimilar metals is not sufficient protection since the introduction of treated well water and softened Colorado River water.

Oil or grease-type coatings applied to moisture free, thoroughly cleaned standard bronze chambers have given complete protection during two and one-half years of field testing. The sustained accuracy and complete absence of corrosion deposits indicate these coatings are probably adequate to cover a normal span of ten years.

Iron case compound meters must have a protective coating on the interior iron surfaces in addition to an oil or grease type coating on bronze parts to give satisfactory performance in treated well water or softened Colorado River water.

Other water works using softened Colorado River water can expect difficulties similar to those noted in field tests at Long Beach.

It is hoped that these observations will prove useful in helping other agencies to minimize galvanic corrosion in water meters or similar devices.

### References

1. Lee Streicher. Effects of Water Quality on Various Metals. *J. Amer. Water Works Assoc.*, **48**, 219-46 (1956) March.

## Epoxy Resin Symposium

Relation of Chemical Structure to the Properties of Some New Epoxy Resins by Douglas D. Applegarth, Dow Chemical Company is one of the papers scheduled for presentation during the October 21 one-day technical symposium scheduled by the Upper Midwest Section, Society of Plastics Engineers, Inc. The symposium will be held at Curtis Motel, Minneapolis, Minn. Ten papers will be given on epoxies.

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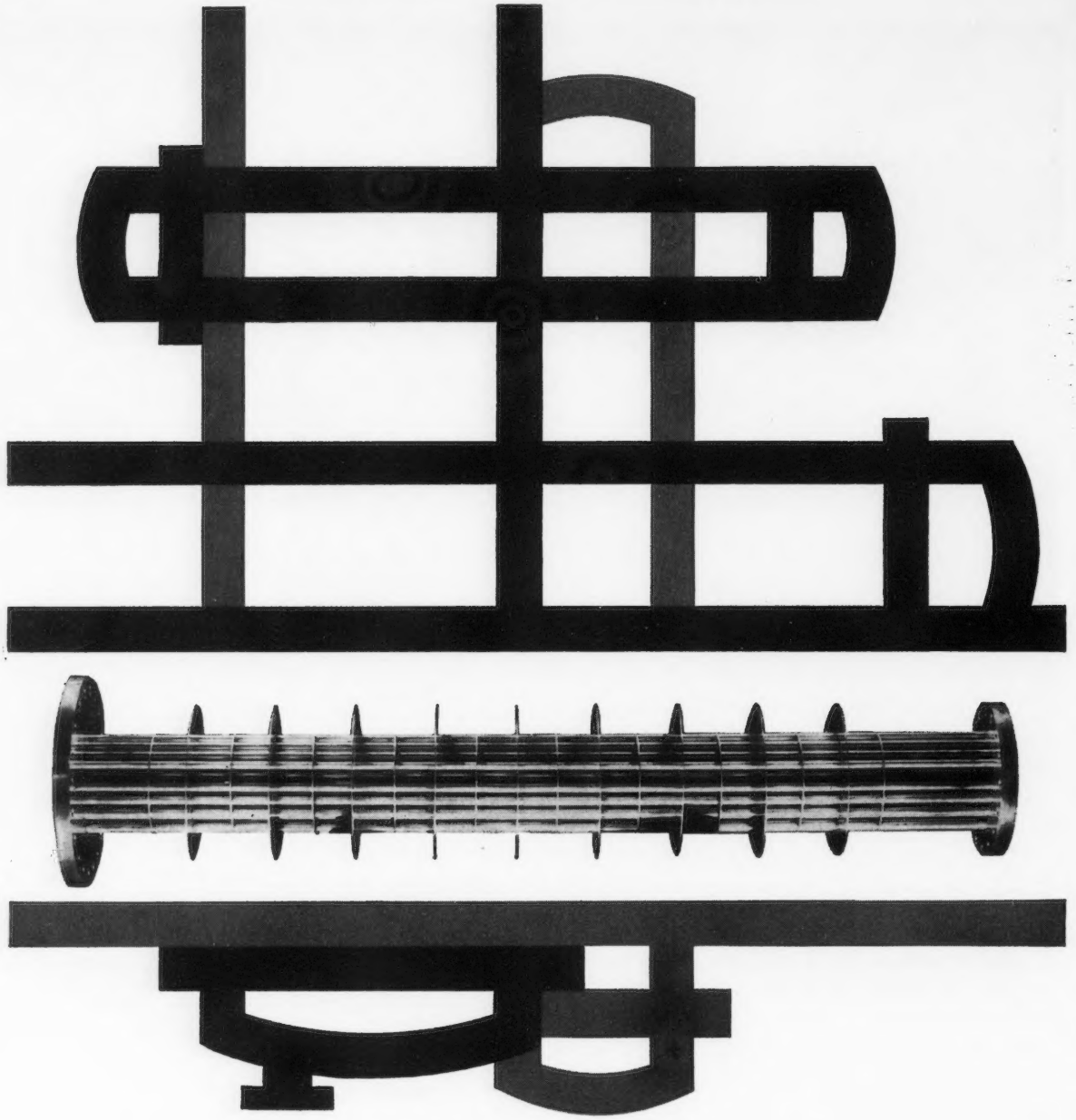

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# CORROSION ABSTRACTS


## INDEX TO CORROSION ABSTRACTS


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## 1. GENERAL

### 1.4 Bibliographies and Indexes

1.4, 2.4.3, 2.3.9

**Non-Destructive Testing.** A Literature Search. RICHARD J. SMITH AND THOMAS W. SCOTT, compilers. Technical Information Service Extension, U. S. Atomic Energy Commission Pubn., TID-3521, November 1957, 11 pp. Available from Office of Technical Services, Washington, D. C.

Bibliographic and availability information is given for 70 Atomic Energy Commission reports and 18 non-Atomic Energy Commission reports in which are described the following nondestructive testing techniques: Sonic, ultrasonic, radiographic, radioautographic, fluorescent penetrant, electromagnetic, frost, eddy current and leak testing.—NSA. 15409

### 1.6 Books

1.6, 3.5.8, 8.9.1

**Papers on Metals.** Am. Soc. for Testing Materials Special Technical Publication No. 196. March 18, 1958, 182 pp. Available from the American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pennsylvania.

This book contains eleven papers covering a wide range of topics associated with the properties of metals and their evaluation.

The increasing need for authoritative technical data in this field spurred by aircraft and missile research makes this a timely and worthwhile collection of papers. Practical experience and sound judgment based on long research are brought to bear upon modern concepts of corrosion, fatigue and strength properties of metals.

The papers were presented at the Second Pacific Area National Meeting in Los Angeles September, 1956. However, it contains current discussion. The papers are: Studies of Stainless Steel Columns Subject to Compression Loads, Julien Dubuc, George Welter and V. N. Krivobok; Shotpeening Effects and Specifications, H. O. Fuchs; The Effect of Forming on Mechanical Properties, J. L. Waisman; Axial Stress Fatigue, Creep and Rupture Properties of Unnotched Specimens of Heat Resistant Alloys, F. H. Vitovec and B. J. Lazan; Determination of Young's Modulus Under Conditions of Relaxation, R. W. Fenn; Effect of a Number of Variables on the Fatigue Properties of High Strength Steels, G. Sachs, B. B. Muvdi and E. D. Klier; The Effect of Temperature Frequency and Grain Size on the Fatigue of High Purity Aluminum, N. H. G. Daniels and J. E. Dorn; Determination of Fatigue-Crack Initiation and Propagation in a magnesium Alloy, Robert B. Clapper and J. A. Watz; Uni-Directional Directional Axial Tension Fatigue Tests of Beryllium Copper and Several Precipitation Hardening Corrosion Resistant Steels, M. H. Weisman, J. Melill and T. Matsuda; The Properties of Beryllium Copper Strip as Affected by Cold Rolling and Heat Treatment, J. T. Richards and Ellsworth M. Smith; Pit Depth Measurements as a Means of Evaluating the Corrosion Resistance of Aluminum in Sea Water, T. J. Summerson, M. J. Pryor, D. S. Keir and R. J. Hogan. 15039

1.6, 3.7.4

**Dislocations and Mechanical Properties of Crystals.** Book. JOHN C. FISHER, editor. 634 pp., 1957. Available from John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, New York.

Proceedings of an international conference held at Lake Placid, New York September 6-8, 1956, sponsored by Air Force Office of Scientific Research, Air Research and Development Command and the General Electric Research Laboratory. The papers were presented at a closed conference by a selected group of specialists in the field of mechanical aspects of dislocations. The discussions were recorded and edited for this volume.

Included are 42 discussions under the following headings: Direct observation of dislocations, deformation of pure single crystals, work hardening and recovery; alloy crystals, impurities and yield point phenomena; dislocation damping and fatigue, theory of dislocations, whiskers and thick crystals, radiation damage. The book is extensively illustrated with photographs, diagrams and graphs related to the material. Appropriate references are appended at section ends.

There is an index of contributors and an alphabetical subject index. 15271

1.6, 5.9.1

**Surface Preparation of Ferrous and Non-Ferrous Metals.** (In German.) W. MACHU. Book, Second Edition, 1957, 960 pp. Akademische Verlagsgesellschaft Geest und Portig, K. G., Leipzig.

This large tome attempts a comprehensive review of methods of surface preparation by the various processes of chemical and electrolytic cleaning, abrasive blasting, barrelling, flame cleaning, pickling, grinding and polishing. Covering such an immense field, it is hardly to be expected that more than brief attention is given to any one subject. For instance, electrolytic polishing is dealt with in 15 pages and chemical polishing in 5½ pages. Nevertheless, the literature references are profuse; thus the eltcro- and chemical polishing sections contain 137 literature references, while the whole book lists 2143 literature references, so that the book will no doubt prove very useful on this score alone.

Comparing this second edition with the first edition, it is seen that the author has considerably expanded the chapters dealing with emulsion cleaners, abrasive blasting, de-burring, barrel grinding, chemical and electrolytic polishing and belt polishing. 15397

1.6, 6.3.15, 3.5.8, 8.9.1

**An Evaluation of Fatigue Properties of Titanium and Titanium Alloys.** J. G.

**Abstracts in This Section are selected from among those supplied to subscribers to the NACE Abstract Punch Card Service. Persons who are interested in reviewing all available abstracts should write to NACE for information on this service.**


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WEINBERG and I. E. HANNA. Titanium Metallurgical Lab., Battelle Memorial Institute, Office of Assistant Secretary of Defense for Research and Engineering. Book, July, 1957, 145 pp. Available from Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C. (Order PB 121631).

This volume was prepared in response to numerous inquiries, from aircraft designers in particular, for information concerning fatigue properties of titanium and titanium alloys. The main objective was to review and evaluate the present knowledge of fatigue behavior of titanium alloys with regard to such factors as notch effects, surface finishes, finishing techniques and environment. Information came from a number of sources including the TML Information Center, the open literature, government agencies, university and company laboratories. Only alloys of commercial interest are included. An appendix contains tables and graphs showing most of the existing data.—OTS. 15135

1.6, 6.3.10

**Nickel and Its Alloys.** National Bureau of Standards Circular 592. Feb. 5, 1958, 87 pp. Available from Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

A revision of Circular 485 (1950) comprehensively covering the origins, refining, uses and properties of nickel. Ferrous and non-ferrous alloys are also investigated. About 800 references are listed. The revision was sponsored by The International Nickel Co., Inc., under the National Bureau of Standards' research plan. 15168

1.6, 6.4.1

**Handbook of the Technology of Wrought Light Alloys.** CARLO PANSERI. Book, 1957, 845 pp. Published by Ulrico Hoepli, Milan, Italy.

The Handbook of the Technology of Wrought Light Alloys is a compilation of the results of 25 years of research and is presented by one of the most outstanding scientists in this field, assisted by a group of equally well known and esteemed collaborators. As the title of the book indicates, it is of predominantly practical character; theoretical considerations and controversial subjects are avoided. The treatment of the material follows a logical pattern; after an introductory part ingot preparation is discussed, the evolution of the microstructure and its practical significance in heat treatment, are studied. Next, corrosion behavior of the various light alloys is analyzed, and several chapters deal with mechanical working, joining and surface treatment. In the concluding part a review of alloy types and their properties


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is presented. An appendix lists the chemical composition of 1225 alloys.—ALL. 15304

1.6, 8.4.5

**Atomic Energy Facts.** U. S. Atomic Energy Commission Pubn. Book, 216 pp., September, 1957. Available from Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

A summary of atomic activities of interest to the industry. The book is identified as the first in a series of books sponsored by the AEC as a part of its industrial information program.

Contents include a discussion of the pattern of atomic energy, economic and manpower requirements, effect on industry, the work of government in the atomic energy program, licenses, patents and industry and international atomic cooperation.

Organization and functions of the AEC are described. Production of uranium and thorium is described with some information on locations of principal ore deposits. Power reactors are extensively considered with data on costs, design, experimental program, fuel cycles, fuel systems, separation processes, waste disposal use of fission products.

Reactor materials are considered for heavy water, with special atention to reactor grade graphite production, beryllium and zirconium. Characteristics of research reactors are detailed and the development and use of isotopes considered.

Appendices give categories of restricted data available to holders of access permits, depositories of atomic data, rules of the commission and extensive tabulated data on power reactors. 15117

## 1.7 Organized Studies of Corrosion

1.7.1

**U.S.S.R. Corrosion Conference.** The Fight Against Corrosion, Proc. U.S.S.R. Corrosion Conf., 1957. U.S.S.R. Academy of Science, Chemical Science Div. *Corrosion Technology*, **5**, No. 1, 31-32 (1958) Jan.

Papers include: Effect of Cathodic Structural Components, by N. D. Tomashov, 135-148; Stainless Steels in $H_2CrO_4$, by M. M. Kurtepov, 89-91; Study of Difference Effect in Corrosion of Stainless Steel, by N. D. Tomashov, 26-33; Effect of Halogen Ions on Corrosion of Stainless Steels in Acid, by S. M. Babitskaya, 69-88; Over-Passivation of Steels in Oxidizing Media, by V. P. Batrakov and G. V. Akimov, 22-25; Inter-Crystalline Corrosion of High Chromium Steels, by L. A. Levin, 34-58; Stainless Steels in Hydrofluoric Acid Solution, by M. M. Kurtepov, 59-68; New Types of Resistant Steel, by A. A. Babakov, 114-134; Nature of Corrosion Resistance of Stainless Steels, by G. V. Akimov, 11-12.—INCO. 15172

1.7.3, 6.4.2, 4.6.2

**Minutes of a Conference on the Corrosion of Aluminum in Water at High Temperatures Held at Chalk River, Ontario, December 18 and 19, 1956.** M. D. FERRIER. Atomic Energy of Canada Ltd. Chalk River Project, Chalk River Ontario, CPMet-700, June 1957, 183 pp. Includes Appendix I: Experiments in Corrosion Mechanism Aluminum at High Temperatures. J. E. Draley and W. E. Ruther. U. S. Atomic Energy Commission Pubn., ANL-5658, Dec.,

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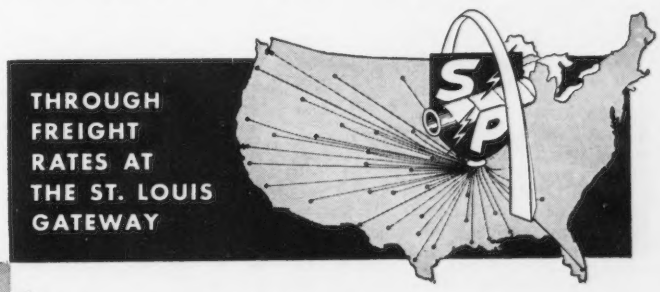


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1956 (Revised April, 1957). Appendix II: Aluminia Properties. A. S. Russell. 1953. (From Alcoa Tech. Paper No. 10).

The methods used at Chalk River to measure the extent of corrosion on aluminum and nickel alloys exposed to water at high temperatures are given. Static corrosion tests, corrosion under flowing conditions, mechanical properties of corrosion resistant aluminum and the actual mechanism of corrosion are discussed.—NSA. 15264

## 2. TESTING

### 2.3 Laboratory Methods and Tests

2.3.1, 6.3.6

**Comparative Study of Stress-Corrosion Testing of Brass and Long-Term Storage Tests.** S. HELLSING, O. LISSNER, S. RASK AND B. STROM. *Werkstoffe u. Korrosion,* **8,** 569-573 (1957) October.

Comparative stress-corrosion tests using mercury nitrate and ammoniacal solutions and evaluation of reliability of results using a long-term corrosion test. —INCO. 15310

2.3.2, 2.3.4, 5.3.4

**The Testing and Examination of Electrodeposits.** V. Porosity Tests. R. QUARENDON. Product Finishing, **10,** No. 11, 70-82, 122 Nov.

The author discusses tests for porosity in electrodeposits. Ferricyanide, salt spray, electrographic and hot water tests are given particular attention and a number of other tests are discussed more briefly. 2 figures.—ZDA. 15416

2.3.2, 5.3.4

**The Testing and Examination of Electrodeposits.** Pt. IV. Atmospheric Tests. R. QUARENDON. *Product Finishing,* **10,** 79-89 (1957) Sept.

Types of atmosphere; test panel arrangements; choice of test articles; accelerated tests; performance criteria; test duration; loss of weight; removing corrosion deposits; visual inspection.—BTR. 15046

2.3.2, 6.4.2

**Detection of Chemical Protective Films on Aluminum and Aluminum Alloys.** A. J. RAFFALOVICH and S. FIRESTONE. *Metal Finishing,* **55,** No. 4, 65, 67 (1957).

Three chromate, three phosphate and a chemical-oxide coating on 3S, 24S, Alclad 24S and 52S aluminum alloys required $<20$ sec. for reaction with a drop of 2N-stannic chloride solution placed on the surface. A black spot was produced in $>60$ sec. If no chemical film is present, a violent reaction occurs in 1-7 sec. and the black spot is formed within 20 sec.—MA. 15032

2.3.2, 8.9.2

**Accelerated Salt Spray Testing of Plated Parts.** G. L. SUKES. Gen. Motors Corp. *Automotive Inds.,* **117,** No. 11, 54-55, 113 (1957) December 1.

Investigations at Cadillac Materials Lab. showed following modification of salt spray test to hold most promise: saturator tower temperature of 130-135 F.; salt fog chamber temperature of 120 F.; salt solution of 5 gal. distilled water, 5% by weight sodium chloride, 5½ grams cupric chloride and pH of 3.2 adjusted with glacial acetic acid; and fog collection rate of 1-2 ml per hour per 80 sq. cm. This modification produced accelerated corrosion on anodized aluminum and copper-nickel-chromium plated steel in 24-48 hours which was approximately a duplicate of that achieved by 192 hours of acetic acid salt spray testing. This accelerated salt spray test has been accepted as standard for General Motors Corp. Tables summarize: preliminary evaluation of accelerated vs acetic acid salt spray tests, salt spray corrosion study test panel data, method for rating plated samples, recommended acceptance standards on anodizing and plating to be used with accelerated salt spray test and operating conditions.—INCO. 15067

2.3.2, 5.3.4

**Accelerated Corrosion Testing of Chromium-Plated Articles—Sulphur Dioxide Test.** J. EDWARDS. Paper before Jt. Mtg. Inst. Metal Finishing and Soc. Chem. Ind., London, October 21, 1957. *Trans. Inst. Metal Finishing,* **35,** 55-78 (1958); *Bull. Inst. Metal Finishing,* **7,** No. 4, 55-78 (1957/1958) Winter; *Electroplating & Metal Finishing,* **11,** No. 1, 17-22 (1958) Jan.

Investigation of accelerated corrosion test employing a humid atmosphere containing sulfur dioxide. Description of apparatus and procedure is given. Permissible variations in $SO_2$ concentration, relative humidity and temperature were examined and it is shown that required conditions can be maintained by simple methods. Corrosion pattern developed closely resembles that produced by outdoor exposure. Reproducibility of results at different times and in different laboratories is good. Range of application covers nickel plus chromium, with and without undercoats of copper or bronze, bronze plus chromium with no nickel and tin-nickel. Limited experience of test on nickel plus chromium-plated brass and copper plus nickel plus chromium-plated zinc alloy diecastings suggests that it is also effective for these materials. Comparative specimens of sulfur dioxide test, acetic acid-salt spray test and outdoor industrial atmosphere exposure are shown.—INCO. 15173

2.3.4

**Rapid Identification of Nitrogen, Phosphorus, Silicon and Titanium in Coating Vehicles.** M. H. SWANN. Aberdeen Proving Ground. U. S. Army. June, 1957, 9 pp. Available from Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C. (Order PB 131291).

A rapid method was developed for group tests used to obtain general classification in the identification of unknown coating systems. It was found that the rapid digestion of coating vehicles with a special Kjeldahl microtechnique can be used for simultaneous detection of nitrogen, phosphorus, silicon and titanium. In one operation requiring about 10 minutes the four elements are prepared for identification. This is a considerable saving of time and work over the usual plan of four separate digestions. The method may also have quantitative application.—OTS. 15417

2.3.4, 5.4.5

**Rapid Detection of Urea- and Melamine-Formaldehyde, Isocyanate and Urethane Resins in Coatings.** M. H. SWANN. Aberdeen Proving Ground, U. S. Army. June 1957 7 pp. Available from Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C. (Order PB 131292).

A new rapid qualitative test was devised for urea and melamine resins and the new isocyanate and polyurethane resins in coating vehicles. The tests are said to be the first specific ones available for these resins which are applicable to all types of coatings. Urea- and melamine-formaldehyde resins in modified alkyds or other coating vehicles are identified simultaneously by refluxing with a mixture of acetic acid and anhydride containing a small amount of p-dimethylaminobenzaldehyde. Isocyanate and polyurethane resins are identified by the same reagent in glacial acetic acid.—OTS. 15418

2.3.6, 3.2.2

**Technique for Direct Observation of Fracture Surfaces Using the Electron Microscope.** W. PITSCH. *Arch. Eisenhuttenw.,* **28,** 663-666 (1957) October.

Details of carbon replica technique for study of fractures, including brittle fractures, in ferritic and austenitic steels. Supporting data are given on 12/18 and 3/1 nickel-chromium steels. —INCO. 14987

2.3.6, 6.3.10

**Etching Technique to Differentiate Between Corrosion-Resistant Nickel-Chromium and Nickel-Chromium- Molybdenum Steels.** F. K. KAUMANN AND W. CARIUS. *Archiv. Eisenhuttenwesen,* **28,** 641-644 (1957) Oct.

Evolution of etching technique to permit works differentiation between molybdenum-free and molybdenum-containing corrosion-resistant nickel-chromium steels. Best results were obtained using etchant consisting of concentrated hydrochloric acid and calcium ferrocyanide solution. Potential application of technique to other materials is discussed. —INCO. 14970

2.3.6, 4.3.5, 6.3.11

**Optical Studies of the Corrosion of Silver by Iodine Vapor.** (In French.) G. COLANGE AND R. DUBRISAY. *Societe Chimique de France,* Bulletin, No. 10, 1225-1228 (1957) Oct. 10.

Interference methods, using a continuous recording apparatus, were used to study variation of the velocity of attack with temperature and depth of attack.—BTR. 15207

2.3.7, 3.5.8, 6.2.2

**Fatigue of Cast Iron.** H. MORROGH. Extracted from chapter of book "Fatigue of Metals," edited by J. A. Pope, Chapman and Hall, Ltd. *Foundry Trade J.,* **102,** No. 2105, 197-202 (1957) Feb. 14; *ibid.,* No. 2106, 239-244 (1957) Feb. 21.

Test pieces and bars for fatigue testing, test piece size and its relation to section size, cycles to determine limiting fatigue, test speed and expression and interpretation of test results in terms of endurance rates and limiting fatigue strength, are considered. Fatigue resistance and notch sensitivity are discussed for flake graphite, malleable and modular cast irons. Effects of under- and over-stressing in fatigue testing are reviewed and crankshaft applications are mentioned. Effects of surface rolling, surface finish, elevated and subzero temperatures and annealing on fatigue properties of flake-graphite and spheroidal graphite irons, are discussed. Graphs.—INCO. 15019

2.3.9

**A New Photographic Method for Investigating the Corrosion of Metals in the Early Stages.** (In Russian.) I. L. Roikh. *J. Phys. Chem.*, USSR (Zhur. Fiz. Khim.), **31,** No. 9, 1959-1963 September.

Automatic method using continuous cleansing was developed for studying atmospheric corrosion during the first few seconds from the beginning of the oxidation.—BTR. 15414

2.3.9, 2.4.3, 5.9.4

**Nondestructive Thickness Measurement of Anodizing Using the Interference Microscope.** Roger L. Saur. *Plating,* **44,** No. 10, 1079-1082 (1957) October.

The interference microscope is used to measure transparent anodic film thickness on aluminum and aluminum alloys in the range 0.00005 to 0.0008-inch with an accuracy of about ± 0.00002-inch. Two sources of light that can be used interchangeably, one white light the other monochromatic, are used with the interference microscope. Anodized film thickness is determined by counting the number of fringes between points on the surface previously established with the aid of white light; no stripping is necessary. The interference microscope was also used to determine the refractive index of the anodic film. This was done by obtaining the ratio of the optical thickness to the mechanical thickness at the edge of a stripped portion of the film. Corresponding samples of Swiss-O, AAEC and AA5357 alloys were anodized under identical conditions and time. It was found that while the anodizing thickness of the corresponding samples of AAEC and AA 5357 alloys were comparable, the anodic films of the purer Swiss-O alloy were appreciably thicker.—ALL. 15081

2.3.9, 6.3.15

**Partition of Soluble Carbon in Titanium-6 Aluminum-4 Vanadium Alloy.** R. D. Seibel, R. L. Beck and L. E. Olds. University of Denver. U. S. Wright Air Development Center, U. S. Air Force. November 1957, 78 pp. Available from Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C. (Order PB 131603).

A useful method was developed for measurement of the microdistribution of embritling interstitial-type solutes in alpha-beta titanium alloys. The method, which was completely independent of the presence of other solute elements, was based upon measurements of either lattice parameters or internal friction A micro-radiographic procedure was devised which may prove useful in checking the results of other techniques. For reasonable exposure times, the method is restricted to carbon contents in excess of 550 parts per million. A technique was also developed for expediting the approximation of X-ray lattice parameters by the successive approximation method.—OTS. 15421

2.3.9

**The Application of Radioactive Tracers to Surface Studies.** R. W. Cahn. *Trans. Inst. Met. Finishing,* **35,** 1-12 (1958).

The paper begins with a brief outline of the preparation and decay properties of radioactive isotopes and of the methods used for locating "tracer" elements


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by photographic means and measuring the intensity of the radiation emitted by them. The exchange of ions between a metal and a radioactive solution containing its own ions is described. This exchange is surprisingly rapid and sensitively dependent upon the state of the surface and on the composition of the solution. The mechanisms involved remain to be elucidated. The electrochemical exchange between a metal surface and ions of another metal in solution casts much light on the heterogeneous nature of metal surfaces, as does the chemisorption of a gas on a metal. These have all been studied by tracer techniques. Another fruitful field of study is corrosion, with special reference to the mechanism of passivation. Minute amounts of material are involved, insufficient to form a surface monolayer and only radioactive methods are sensitive enough to follow the behavior of these trace amounts. Electroplating at low current densities and metal transfer in friction are other topics reviewed. (auth)—ALL. 15179

**2.3.9, 1.6**

**Radioisotopes.** Am. Soc. for Testing Materials Special Technical Publication No. 215. March 18, 1958, 100 pp. Available from the American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pennsylvania.

This symposium covers testing techniques utilizing radioisotopes and demonstrates the wide range of industrial applications to which they may be put. Changes in physical properties of materials as a result of radiation are discussed in some of the papers. Extensive references and many illustrations may be found in the book.

In the symposium the reader will find broad information on radioisotope tracing. Case histories are presented ranging from electroplating studies, the evaluation of rubber deterioration and the mechanism of detergency, to the analysis of trace materials by neutron irradiation and the achievement of process control via tracers during full-scale petroleum refinery operations.

The papers on precision industrial gaging of either moving or static solids and solutions will suggest to the reader a wealth of opportunities for future standards and useful applications. The papers are: Introduction, Charles E. Crompton; Electroplating and Metal Preservation Studies Utilizing Radioisotopes, Stanley L. Eisler; Evaluation of Rubber Deterioration by Means of Phosphorus-32, J. F. Young and C. W. Richards; Autoradiography as a Testing Technique, Milton J. Schlesinger and Henry J. Gomberg; Use of Radioactive Tracers in the Study of Soil Removal and Detergency, E. B. Ashcraft; Refinery Scale Applications of Radioactive Tracers, V. P. Guinn, H. R. Lukens, Jr. and C. D. Wagner; Activation Analysis for Industry, Abel DeHaan; Thickness, Density and Concentration Gaging with Radioisotopes, R. L. Newacheck, J. Kohl and D. L. Forrest; Will ASTM Standards be Influenced by Radiation Effects in Metals?, J. C. Wilson and R. G. Berggren; The Problem of Establishing Specifications for Irradiated Organic Materials, O. Sisman; General Discussion, Paul C. Aebersold. 15040

**2.3.9, 2.4.2, 8.9.1**

**Research and Development Leading to the Establishment of Ultrasonic Test Standards for Aircraft Materials.** A. D. GUINN, R. D. MCKOWN, J. C. FOLZ AND W. C. HITT. Ultrasonic Testing and Research Laboratory, U. S. Wright Air Development Center, U. S. Air Force, October, 1957, 133 pp. Available from Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C. (Order PB 131564).

Ultrasonic testing is recognized by material producers and engineers as one of the best nondestructive methods of testing metallic materials for subsurface discontinuities. Data contained in this volume provide assistance in setting up reference standards for ultrasonic testing of various alloys. It was compiled from results of the determination of signal response variables which may be caused by manufacturers' method, such as rolling or forging, the conditions of heat treatment, grain flow direction, differences in machined surface finishes, different surface angularity and the effects of various convex and concave radii machined on the top surface. Comparisons are made between test results obtained from different alloys of the same group, different crystals and various frequencies and gain settings.—OTS. 15282

## 2.4 Instrumentation

**2.4.2, 2.3.2**

**Corrosion Testing—the Villanova Cycling Machine.** G. N. QUAM, D. SCHWARTZ AND W. BARNHURST. Villanova Univ. *Ind. & Eng. Chem.*, **49,** No. 10, 85A-86A (1957) October.

Description of corrosion testing machine which cycles temperatures and humidity, giving dew points at an accelerated rate and produces heating of specimen while covered with condensed water. Villanova cycling machines have satisfactorily simulated selected weather conditions on much accelerated basis in present evaluation of commercial inhibitors. Photographs.—INCO. 15031

**2.4.2, 8.9.4**

**Nondestructive Testing Applied to Railroad Materials and Equipment.** A. S. PEDRICK. Paper before Am. Soc. for Testing Materials, 2nd Pacific Area National Meeting, Symposium on Nondestructive Testing, Los Angeles, September 17-18, 1956. ASTM Special Technical Pubn. No. 213, 21-34; disc., 35 (1957).

Reviews surface examination and crack detection of railroad equipment by means of magnetic particle inspection, Zyglo fluorescent penetrant inspection, and Magnaglo inspection, as well as detection of internal flaws by ultrasonic reflectroscope inspection, rail detector devices, radiographic examination, and high-intensity black light. Zyglo penetrant is used for inspection of Diesel valves which will not take satisfactory magnetic tests due to high percentage of chromium or nickel. Photographs show corrosion fatigue cracks in passenger car axle, silicate inclusion in Diesel axle, as well as flaws in Diesel valves and piston carrier.—INCO. 15381

**2.4.3, 6.3.20**

**Developmental Work on Non-Destructive Test Methods of Inspecting Subassemblies for Corrosion.** FRANK CAIN, JR. AND RICHARD ALTO. Westinghouse Electric Corp. U. S. Atomic Energy Commission Pubn., WAPD-MP-75, May 13, 1952 (Declassified April 15, 1957), 8 pp. Available from Office of Technical Services, Washington, D. C.

Methods which could be used to distinguish between a corroded zirconium surface and a non-corroded one are reviewed and evaluated. The major limitation was the proximity of the plates to be examined in the fuel subassembly. —NSA. 15200

**2.4.3, 8.4.3, 2.3.9**

**Non-Destructive Techniques in Refinery Inspection.** P. W. SHERWOOD. *Corrosion Technology,* **4,** No. 5, 148-151 (1957).

Methods reviewed include: measurement of thickness and detection of cracks by magnetic, electrical and ultrasonic methods; detection of flaws with $\gamma$- and X-rays.—MA. 15092

## 3. CHARACTERISTIC CORROSION PHENOMENA

### 3.2 Forms

**3.2.2, 6.4.2, 3.7.4**

**Some Observations on the Structure of Grain Boundary Fracture Surfaces (Aluminium-20% Zinc).** H. C. CHANG AND N. J. GRANT. *J. Metals* (Trans. AIME), **8,** No. 10, Sec. 2, 1241-1247 (1956) October.

Fracture surface studied by microscopy and X-rays.—BNF. 13548

**3.2.2, 5.3.2, 3.5.5**

**The Inhibition of Electrical Diffusion of Hydrogen Through Iron and Steel by Surface Films of Some Metals.** L. I. FREIMAN AND V. A. TITOV. *J. Phys. Chem., USSR* (Zhur. Fiz. Khim), **30,** No. 4, 882-888 (1956); *Chem. Absts.,* **50,** 16241 (1956) Nov. 25.

Study of diffusion of hydrogen through electrodeposited nickel, copper, lead and tin films in presence of catalyst poison $NaAsO_2$ in sulfuric acid electrolyte, using platinum disc as anode. Nickel and copper films inhibited diffusion.—INCO. 13576

**3.2.2, 6.2.3, 2.3.7**

**Experiments on the Arrest of Brittle Cracks in 36-Inch Wide Steel Plates.** A. A. WELLS, P. H. R. LANE AND G. COATES. Brit. Welding Res. Assoc. Rept. FE. 19/48/56. *Brit. Welding J.,* **3,** No. 12, 554-570 (1956) December.

Tests described were designed to investigate relative effectiveness of different types of plate structure in stopping a running brittle crack. Specimens were made from 5/8-inch thick plates of ship quality steel (0.12 and 0.11 nickel), constructional steel (0.14 nickel) and fully killed steel (0.09 nickel). Brittle cracks were initiated in plain plates and in composite specimens, both welded and riveted. Tests were carried out with BWRA. Wide Plate Testing Rig in which loads up to 600 tons can be generated by means of oil-filled pressure capsules; description of machine is given. Results are also given for Charpy V impact, Tipper notch tensile and Robertson crack arresting tests performed on the same steels; data range down to —80 C. Graphs, photomicrographs.—INCO. 13719

**3.2.2, 6.2.5, 3.7.3**

**Further Studies on Stainless-Steel Hot Cracking.** P. P. PUZAK AND H.

RISCHALL. Naval Research Laboratory, Nov., 1956, 12 pp. Available from: Office of Technical Services, U. S. Dept. of Commerce, Washington, D. C. (Order PB 121569).

Sporadic base-metal hot cracking and weld-metal hot cracking are generally encountered in the welding of heavy sections of the columbium-bearing Type 347 stainless steels. Results of this research support an hypothesis drawn from earlier studies that grain-boundary liquation is responsible for base-metal hot cracking. Additional findings for a Type 347 heat (which was previously found most susceptible to hot cracking) were compared with those for a standard Type 304 heat (which was not susceptible). Liquation and solidus temperatures were obtained by thermal-analysis techniques. The hot ductility and strength measured in the temperature range immediately below the region of normal incipient melting were low only for those heats which exhibited base-metal hot cracking. Microscopic examination of these specimens revealed the presence of grain-boundary liquation areas, corroborating evidence for the liquation-cracking hypothesis. A eutectic-type mixture of carbides and nitrides of columbium with minor amounts of manganese, silicon and iron was suggested as the probable segregate composition involved in liquation cracking of the Type 347 alloys. 13675

## 3.5 Physical and Mechanical Effects

3.5.8, 1.7.1

**Reports on Fatigue Failure.** Commission XIII on Fatigue Testing. International Inst. of Welding. *Brit. Welding J.*, **4**, No. 5, 231-238 (1957) May.

Reports on fatigue failures occurring in service in welded constructions with following information given for each case: type of construction, stresses in normal service where failure occurred, fracture and circumstances in which it appeared, composition of materials in region of failure, type of welded joints affected, their dimensions, welding conditions, and presumed causes of the accident. Cases discussed are: 18-8 plate in axle arm of washing machine; front axle of truck; 400-ton mild steel hydraulic press frame; cast stainless steel mixing arms; and mild steel pipe-flange junction in air compressor. Photomicrographs.—INCO. 14570

3.5.8, 3.7.4

**Stress Corrosion in Homogeneous Alloys, Its Condition and Its Mechanism.** (In German.) L. GRAF. *Werkstoffe u. Korrosion*, **8**, 329-344 (1957) June.

The most important factor influencing the susceptibility of homogeneous mixed crystals to stress corrosion cracking is the mixed crystal concentration. The reactivity along "large angle" grain boundaries and glide planes increases considerably with mixed crystal concentration, reaching a maximum at 50 at. %. Under the influence of chemical agents the mixed crystal effect is noticeable only if the attack is supported by an electrochemical process. Tensile stress is effective only if it causes local, plastic deformation. 25 references.—BTR. 14639

3.5.8, 8.2.1

**Fatigue, Creep, and Relaxation in Metals.** G. R. GOHN. Bell Labs. Record, **35**, No. 6, 201-205 (1957) June.

Defines fatigue, creep, and relaxation in metals, and explains how these properties indicate how well-suited a metal is to the operating stresses it will encounter in particular applications. References are made to failures in telephone equipment. Machine switching, because of increased demands on relays, made spring failure a problem. Changing spring material from brass to nickel silver or phosphor bronze resulted in longer life due to higher fatigue strengths of these two materials. In cable sheathing, lead-1 antimony is best in resisting fatigue due to slow cyclic stress, whereas Chemical lead (natural lead containing small percentage of silver and copper) is used for sleeves where creep is predominant. Graphs, photomicrographs.—INCO. 14637

3.5.8

**Fatigue Resistance of Simulated Nozzles in Model Pressure Vessels.** G. WELTER AND J. DUBUC. Paper before Am. Welding Soc., Nat'l. Spr. Mtg., Philadelphia, April 8-12, 1957. *Welding J.*, **36**, No. 6, 271s-274s (1957) June.

Summarizes all observations concerning fatigue resistance of simulated nozzles made during fatigue tests on model

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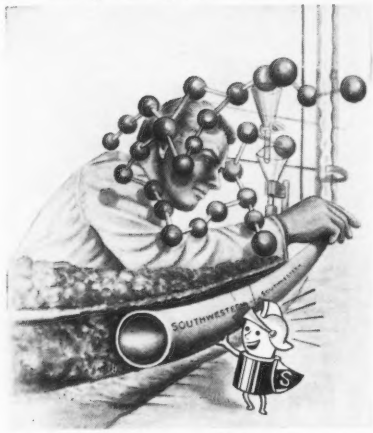

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pressure vessels of A201, Grade A, and A302, Grade B steels under cyclic internal pressure. It was observed that all fatigue fractures occurred in the longitudinal direction of the pressure vessels and began at points of maximum circumferential stress concentration at edge where nozzle hole meets with internal surface of pressure vessel shell. Crack pattern is the same for both steels tested. Table, graph.—INCO. 14358

**3.5.8**
**A Note on the Metallography of Cracking During Creep.** D. McLEAN. *J. Inst. Metals,* **85,** Pt. 2, 468-472 (1957) July.

Microspecimens of Nimonic 80, 80A and 90, G32 and Rex 337A, broken in creep tests at various stresses and temperatures, were examined in study of inception of fracture under different conditions. Few cracks were observed in Nimonic 80 specimens. Cracking phenomenon was clearly shown in other specimens. Stress was controlling factor. At low stress, fracture begins by formation of isolated cavities lying mainly in transverse grain boundaries; at high stress, fracture starts with cracks which are produced by relatively large stress concentrations. In Rex 337 A these cracks lay inside grains, but in other materials they were located at grain corners. Minimum stress needed to produce cracks is sufficiently below calculated minimum to suggest that cohesion in these alloys is lower than in pure metals. Tables.—INCO. 14717

**3.5.8, 3.8.4, 6.4.4**
**Some Observations on Stress-Corrosion Cracking of Single Crystals of AZ61X Magnesium Alloy.** F. MELLER AND M. METZER. Columbia Univ. U. S. National Advisory Cttee. for Aeronautics Tech. Note No. 4019, July, 1957, 23 pp.

Exploratory tests were made of stress-corrosion cracking of single crystals of solution-treated AZ61X magnesium alloy in distilled water, in 0.5 and 1 percent hydrofluoric acid, and in salt-chromate solution consisting of 35 grams of sodium chloride and 20 grams of potassium chromate per liter. In the most successful of the tests, the basal plane was at intermediate angle to the specimen axis; in all corrodents, specimens failed at nominal tensile stresses of 3,500-4,300 psi; pronounced basal slip preceded cracking and failure started at an angle of 70-90 degrees from basal plane. Path chosen by crack is attributed to mechanical rather than electrochemical factors and possible importance of prior deformation is pointed out. 14729

## 3.8 Miscellaneous Principles

**3.8.4, 3.4.9, 6.4.4**
**Metal-Water Reaction. Pt. V. Kinetics of the Reaction Between Magnesium and Water Vapor.** HARRY J. SVEC AND DALE S. GIBBS. Iowa State College. *J. Electrochem. Soc.,* **104,** 434-439 (1957) July.

The rate of reaction between magnesium and water vapor was studied in the temperature range between 425 and 575 C and in the water vapor pressure range between 31 and 208 mm. Hg. The reaction took place according to the linear rate law. Rate constants were found to be linearly dependent on the water vapor pressure. The activation energy for the reaction was found to vary with both temperature and water vapor pressure, increasing as the temperature was increased and the water vapor pressure was decreased. This type of variation is explained on the basis of a change from a surface to a vapor phase reaction due to the very large increase in the vapor pressure of magnesium metal in the temperature range between 500 and 600 C. (auth).—NSA. 14749

**3.8.4, 3.7.2**
**Oxidation Behavior of Metals and Alloys in the Molten State.** (In Italian.) P. SPINEDI. *Metallurgia Italiana,* **49,** 363-370 (1957) May.

Lead, cadmium, tin and zinc were subjected to hot oxidation; behavior in both solid and liquid phases was studied, with emphasis on latter. Binary alloys of these metals were then studied to determine influence exerted on their oxidation behavior by varying concentrations of components. Simple eutectic diagrams were studied, as well as influence on oxidation behavior of intermetallic compounds (cadmium-copper diagram) and by superlattices (cadmium-magnesium diagram). Analogies between oxidation-concentration curves obtained and those reported in recent studies on viscosity, castability, surface tension, etc., in relation to concentration. 40 references.—MR. 14779

**3.8.4, 6.3.21**
**Oxidation of Hafnium.** (In English.) W. W. SMELTZER AND M. T. SIMNAD. Carnegie Inst. of Technology. *Acta Metallurgica,* **5,** 328-334 (1957) June.

Hafnium oxidation rates at 760-mm. oxygen pressure in the temperature range 350 to 1200 C have been represented by logarithmic, parabolic, and linear-rate equations. The respective activation energies for the rate constants were 11.4, 36.0, and 26.1 kcal/mole. The value of the parabolic rate constant was independent of oxygen pressure in the range 10 to 760 mm. Transformation from parabolic linear oxidation was caused by formation of duplex scale of inner compact and outer porous oxides. Monoclinic $HfO_2$ was identified as the surface oxide by X-ray examinations; marker measurements showed that oxygen diffused inward through the oxide to react with hafnium at the metal/oxide interface. (auth)—NSA. 14783

**3.8.4**
**On the Mechanism of the Oxidation of Metals.** D. A. VERMILYEA. *Acta Metallurgica,* **5,** No. 9, 492-495 (1957) Sept.

During the low-temperature oxidation of a metal whose oxide is a cation conductor, it is assumed metal atoms enter the oxide only at lattice steps on the metal surface and that new oxide forms only at the oxide-atmosphere interface. It is shown that if these assumptions are valid there should be almost no stress in oxide films in which cation conduction predominates, that the Pilling-Bedworth rule has no validity for such oxide films, and that no vacancies or voids should be produced in the underlying metal. Some observations of anisotropy of oxidation rate on different crystal faces are discussed. For oxides in which anion conduction predominates it is concluded that there may also be no stress in the film and that the Pilling-Bedworth rule may not apply. (auth)—ALL. 14823

**3.8.4, 6.3.15**
**Mechanisms in the Oxidation of Titanium.** W. M. ALBRECHT. Battelle Memorial

Inst., Titanium Metallurgical Lab., Columbus, Ohio, August 5, 1957, 12 pp.

The oxidation of titanium follows four different rate laws in the range 25 to 1200 C. A protective blue-gray film is formed when the oxidation follows logarithmic, cubic, or parabolic rates at 25-350 C, 350-650 C, and 650 to 825 C, respectively. The film is principally substoichiometric rutile, which is a n-type semiconductor. The reaction proceeds by anion diffusion to the metal-film interface to produce more oxide. The controlling process depends upon which rate law is being followed. Above 825 C the reaction follows principally a linear rate, in which a non-protective film is formed. (auth).—NSA. 14874

3.8.4

**Optical Measurement of Film Growth on Silicon and Germanium Surfaces in Room Air.** R. J. ARCHER. *J. Electrochem. Soc.*, **104**, 619-622 (1957) Oct.

Thickness and growth kinetics of oxide films on polished silicon and germanium exposed to room air after having been rinsed in hydrofluoric acid were obtained by measuring the ellipticity of reflected polarized light.—BTR. 14868

3.8.4, 3.7.4

**Kinetics and Mechanism of Formation of Anode Films on Single-Crystal InSb.** J. F. DEWALD. *J. Electrochem. Soc.*, **104**, 244-251 (1957) April.

Studies of the kinetics-of-formation and composition of anode films on several crystal faces of indium antimonide are reported. A marked dependence of oxidation rate on crystal face is observed at low fields, the (111) and (332) faces oxidizing at more than ten times the rate of the (110) and (111) and (332) faces. At high fields all faces oxidize at the same rate. Data are interpreted in terms of the detailed structure of InSb and the theories of Cabrera and Mott and of Dewald. With one major exception, the composition effects, the data may be qualitatively understood in terms of these theories. 14641

## 4. CORROSIVE ENVIRONMENTS

### 4.3 Chemicals, Inorganic

4.3.2, 5.8.2, 6.2.3

**Semi-Coke Tar Bases: An Effective Corrosion Inhibitor for Steel in Acid Solutions.** K. S. KURYNDIN, E. A. NIKONOVA, I. S. LIVSHITS, A. M. EGOROV AND A. B. EGOROVA. *Khimiya i Tekhnologiya Topliva i Masel (Chemistry and Technology of Fuel and Oils)*, No. 3, 57-62 (1957).

Experiments showed such inhibitors (0.5 percent by wt.) reduced steel corrosion 5-10-fold in 10 percent sulfuric acid and 50-80-fold in 20 percent sulfuric acid at 18-22 degrees. Sodium chloride and hydrochloric acid were found to increase this inhibiting action 100-150-fold. Four tables, four references. ATS. (Translation available: Associated Technical Services, P. O. Box 271, East Orange, New Jersey.) 13810

4.3.3, 5.3.4

**Nickel-Lined Steel Vessels for Caustic Service.** J. L. WEIS. Diamond Alkali Co. *Ind. and Eng. Chem.*, **49**, No. 6, 69A-70A (1957) June.

Describes procedure used to line corroded steel vessels with nickel. Cracks, caused by stress corrosion, are detected by magnetic particle inspection, and then welded. Ductile nickel-to-steel weldments are made with metallic arc electrode. Welding small nickel pads over plug holes and strips over butt joints, was replaced by lap joints as method of assuring uniform corrosion resistance. Thickness of nickel lining is based on compromise of such factors as weight, size, mechanical requirements, and welding procedure. Optimum lining thickness for majority of applications is 0.109 in.—INCO. 14421

4.3.3, 6.4.2

**Dissolution of Aluminium in Alkaline Solutions.** S. HEATH AND G. TOLLEY. *Chemistry and Industry*, No. 12, 367-368 (1957).

A note. Rates of solution of superpurity aluminum in aqueous potassium hydroxide and in a given aqueous-alcoholic potassium hydroxide solution were linear with time for immersions up to 75 min., over the range 0.00667-0.2M at 25-35 C. Study of the rate relationship with alcohol content showed pronounced peaks at ethyl alcohol concentrations of ~60 g./100 cc of solution, similar curves being obtained with propyl alcohol but not with methyl alcohol or ethylene glycol. A flaky, white precipitate covering the surfaces of the aluminum specimens was occasionally observed with ethyl and propyl alcohol when the alcohol concentration was >55 g./100 cc. —MA. 14607

4.3.3, 3.5.8

**Some Aspects of the Stress Corrosion of Steel in Caustic Soda Solution.** F. A. CHAMPION. Paper before Soc. Chem. Industry, Corrosion Group and Yorkshire Section, Nov. 5, 1956. *Chemistry and Industry*, No. 28, 967-975 (1957) July 13.

Discusses stress corrosion of steel plant handling caustic soda solutions in Bayer extraction process. Most important factors in caustic cracking appear to be tensile stress, sodium hydroxide concentration and temperature, and within ranges experienced in Bayer process, a rise in any of these accelerates stress corrosion. Service experience with steels and cast iron is described. Serious cracking can probably be avoided by keeping uncombined soda concentration below 200-250 g.p.l. sodium oxide or temperature below 85 C. Replacement of mild steel by cast iron appears to be plant change which can be relied on at present to attain immunity. With mild steel, most effective precaution comprises thermal relief on the complete plant. Careful fabrication and assembly can reduce residual stresses to a lower level with riveted than with welded structures, but good design and good technique can help considerably with welded structures. Nickel and nickel clad steel are less susceptible to caustic cracking, but not definitely immune and do not seem economically justifiable. Photomicrographs, tables, 16 references. —INCO. 14617

## 5. PREVENTIVE MEASURES

### 5.3 Metallic Coatings

5.3.1

**Structure of Alloy Electrodeposits: Nickel-Zinc Alloys.** E. RAUB AND F. ELSER. *Metalloberflache*, **11**, 165-168 (1957) May.

Discussion of effect of zinc content in nickel electrolytes on the properties of the nickel deposits. Effect on deposition potential of the nickel of adding zinc to nickel electrolytes (a Watts bath and a chloride bath), and investigation of zinc content of nickel-zinc coatings as a function of bath temperature, current density, and zinc content, and of adding toluene sulphonamide to the Watts bath are described. Structure of a series of the alloys was investigated with reference to the phase diagram, $\alpha$ and $\gamma$ phases (but not the $\beta$ and $\delta$) being found. Crystallization of the $\gamma$ phase produces faulty nickel coatings.—INCO. 14314

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5.3.2

**Corrosion Resistance of Glossy Zinc Deposits.** (In German.) HANS-JOACHIM BRINKMANN AND EMIL KNOLL. *Metallwaren-Ind. u. Galvano-Tech.*, **48**, 31-33 (1957) January.

Two factors are of importance in retarding corrosion in galvanizing: 1) thickness of the zinc layer and passivation treatments, and 2) length of interval between individual procedures and intensity of rinsing.—MR. 14546

5.3.2

**Metallization by Spraying in the Struggle Against Corrosion.** (In French.) M. CAUCHETIER. *Corrosion et Anti-Corrosion*, **5**, 156-159 (1957) May.

Metallization by the Schoop process has always given interesting results for zinc, although much less so for other metals. Reviews the principal sprayed metals currently used in France as protective coatings in corrosion control and specifies thicknesses employed; cites a number of uses for metallized parts.—MR. 14600

5.3.2

**The Influence of Manganese on the Plating Alloy of the Ergalplat 55 and 65 Alloys.** (In Italian.) A. PRATI, A. GRATNANI AND D. GUALANDI. *Alluminio*, **26**, No. 7/8, 301-314 (1957) July/Aug.

Two alloys of the Ergal type, the one containing 6.21 percent zinc and 2.72 percent magnesium (Ergal 55), the other 8.06 percent zinc and 2.56 percent magnesium, both with and without copper, were plated with aluminum-zinc-manganese and aluminum-zinc alloys. It is demonstrated that the former plating alloy is to be preferred because the addition of manganese increases the hardness, makes less intense the diffusion of alloying elements from the base metal, and improves the corrosion resistance of the plated alloy.—ALL. 14789

5.3.2

**The Mechanism of the Protection of Steel by Sprayed Aluminum Coatings.** J. E. O. MAYNE AND D. VAN ROOYEN. *Chemistry and Industry*, No. 23, 718-721 (1957) June 8.

In sea-water the rate of attack on the aluminum is sufficiently fast for the steel to be cathodically protected. In tap-water no evidence for cathodic protection was obtained and protection may be due to the blockage of pores in the sprayed coating.—BTR. 14714

5.3.2, 8.9.1

**How Corrosion Is Reduced on Landing Gear Pistons.** WILLIAM L. AVES, JR. *Plating*, **44**, No. 11, 1175-1179 (1957) Nov.

A solution to a corrosion problem on hard chromium plated functional aircraft parts exposed to atmospheric conditions is presented. Although process qualification tests were considerably more extensive than the listed corrosion tests, they were not considered fundamental to the scope of this paper. The double zincate, copper, nickel, chromium process as presently employed on exposed hard chromium plated functional aircraft landing gear parts has adequately protected these parts against corrosion in service. The double zincate, copper, chromium process as originally employed on similar landing gear components proved inadequate in the prevention of corrosion. A detailed method for applying zinc, copper, nickel, and chromium deposits to aluminum alloy landing gear pistons is presented. Test results obtained from corrosion panels also are included. (auth.)—ALL. 14853

## 8. INDUSTRIES

### 8.4 Group 4

8.4.3, 8.9.3, 5.2.1

**Cathodic Protection of Offshore Structures and Submerged Piping Systems in the Gulf of Mexico.** A. H. MASSAD AND B. G. HOLMES. Paper before Am. Petroleum Inst., Production Div., Shreveport, March 20-21, 1957. *Petroleum Engr.*, **29**, No. 5, B73-B74, B76, B80 (1957) May.

Magnolia-Continental-Newmont group reaps installation, power cost savings and extends service life by effective selection and placement of submerged protective systems. Structures above wetted surfaces are adequately protected with a paint system and Monel sheathing is used for protecting splash zone. Cathodic protection systems offer most effective means of protecting underwater zone. Installations required for cathodic protection of submerged facilties and piping equipment are described. Diagrams.—INCO. 14315

8.4.3, 5.8.2, 5.7.7

**Low-pH Receiver Waters Cut Corrosion.** J. A. BIEHL AND E. A. SCHNAKE. *Oil Gas J.*, **55**, 157 + 5 pages (1957) May 20.

Operation and corrosion studies of a crude-oil unit at high and low pH of overhead waters showed that the pH of the receiver waters should be reduced to about 4.3, with inhibitor injections varying from 10 to 15 p.p.m.—BTR. 14572

8.4.3

**Corrosion: Special Report.** *Petroleum Week*, **5**, No. 3, 31-36, 41-42, 45-52 (1957) July 19.

Discusses causes of corrosion and preventive measures being used in all phases of petroleum industry. Topics include: prevention of external and internal attack of delicate seismic instruments used in exploration; corrosion of rigs, casing and drill-pipe caused by drilling muds, acids, treating fluids, etc.; in production, the corrosion of expensive pumps, sucker rods, casing and tubing; problems encountered in pipelining; in refining, natural gasoline processing and petrochemical operations, problems arising from sour crudes, hydrogen sulfide gas, high temperatures and pressures, and high volatility of products handled; corrosion of tankers and barges, offshore drilling rigs and production platforms; and protection of storage and service facilities in marketing. Preventive measures include coatings, inhibitors, sacrificial anodes and cathodic protection.—INCO. 14743

8.4.5, 5.7.6, 4.3.3

**Remote Control Determination of Corrosion Products and Additives in Homogeneous Reactor Fuel: Application of Ion Exchange.** A. D. HORTON, P. F. THOMASON AND M. T. KELLEY. Oak Ridge National Lab. *Anal. Chem.*, **29**, No. 3, 388-391 (1957) March.

Presents ion exchange techniques applied to remote control separation of metal corrosion products from uranyl sulfate solution in homogeneous reactor fuel. Metal in effluent is collected in calibrated polarographic cell sample holder, effluent is dryed, redissolved, and diluted to volume with proper supporting electrolyte. Dowex 1 anion resin is used in chloride and sulfate forms and Dowex 50 cation resin is used in hydrogen form. Adsorption characteristics and separation procedure are tabulated for aluminum, nickel, cobalt, chromium, iron, manganese, copper and zirconium. —INCO. 13803

8.4.5, 4.3.3, 6.2.5

**The Effect of Irradiation on the Corrosion of Type 347 Stainless Steel by Uranyl Sulfate Solutions.** F. H. SWEETON, M. D. SILVERMAN AND H. O. DAY. Oak Ridge National Lab. U. S. Atomic Energy Comm. Pubn., ORNL-2284, May 9, 1957, 31 pp. Available from Office of Technical Services, Washington, D. C.

Techniques were adapted for determining the corrosion of a metal exposed to a fissioning uranyl sulfate solution. A method based on the consumption of oxygen by the metal was found to be extremely useful for following corrosion both in and out of reactor radiation. A

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comparison with two other independent methods shows the technique to be reliable. Instrumental reproducibility of the order of 0.0014 mil was shown for an oxygen measurement, and the overall results for similar corrosion tests have differed by no more than a factor of 2. From these exploratory experiments, it appears that reactor radiation above a power-density level of 4 w/ml causes a sharp rise in the corrosion rate. Radiation effects are not observed until after an initial induction period, which appears to depend on the amount of previous nonradiation exposure. The effect of temperature is apparently minor in the range 250 to 290 C. The pertechnetate ion at a concentration of 0.0005 *m* is apparently not an effective corrosion inhibitor in this system. It is recommended that these studies be continued to improve the experimental method and to obtain a better understanding of the variables affecting corrosion in these systems. (auth.)—NSA. 14371

## 8.8 Group 8

8.8.1, 4.3.2

**Phosphoric Acid by the Clinker Process.** C. C. Legal, Jr., N. J. Pryor, T. O. Tongue and P. L. Veltman. Paper before Am. Chem. Soc., 120th Mtg., Fertilizer and Soil Chem. Div., Atlantic City, September, 1956. *Ind. and Eng. Chem.*, **49**, No. 3, 334-337 (1957) March.

Strong, wet, relatively pure phosphoric acid is obtained directly from phosphate rock without concentration in process described. Dried and ground phosphate rock and strong sulfuric acid are mixed in proportion to form putty-like solid and convert all calcium oxide to calcium sulfate anhydrite with slight excess of sulfuric acid. All phosphorus pentoxide is converted to phosphoric acid. Reaction product is heated at 200-240 C for 20-60 minutes to form hard clinker. Phosphoric acid is separated from insoluble calcium sulfate by counter-current extraction using filtration or leach tank system. Corrosion tests conducted to determine best construction materials for contact with phosphoric acid showed lead and Type 316 were best for use in leach tanks and filters. Aloyco 20, Carpenter 20 stainless steel and Teflon gave good results but were limited due to expense. Nickel and Monel were completely corroded. Mild steel gave satisfactory service for mixer shell. Suitable material for mixer blades remains a problem. Table summarizes corrosion data—INCO. 13811

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## 8.9 Group 9

8.9.4, 3.6.6, 6.6.5

**Pre-Stressed Concrete Sleepers Tested for Service on Electrified Railways.** Railway Technical Research Institute, Japanese National Railways, Tokyo, Japan. *Corrosion*, **13**, No. 8, 120 (1957) Aug.

Two and one-half years tests of buried prestressed concrete railroad sleepers under constant electrical load showed: Wooden plug type connected to anodic end of electrical current deteriorated rapidly, piano wires corroded apart and concrete spalled away. Wooden plug type connected to negative end of current source showed little change. Insulating plug type sleepers showed no damage at either end of circuit. 14382

8.9.5, 3.6.8

**Polarization in the Corrosion of Ice Breakers.** J. H. Greenblatt. *Corrosion*, **13**, No. 12, 817t-820t (1957) Dec.

Measurement of polarization characteristics of steel coupons subjected to the usual treatments given ship plating indicate that cathodic depolarization is the major factor influencing the corrosion observed. At low temperatures in oxygenated water considerable anodic polarization occurred which would tend to mitigate corrosion in low temperature oxygenated waters. Results are discussed in terms of observed corrosion patterns on the hulls of vessels operating in ice. 14497

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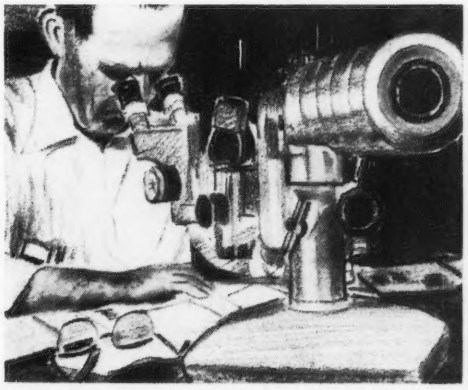

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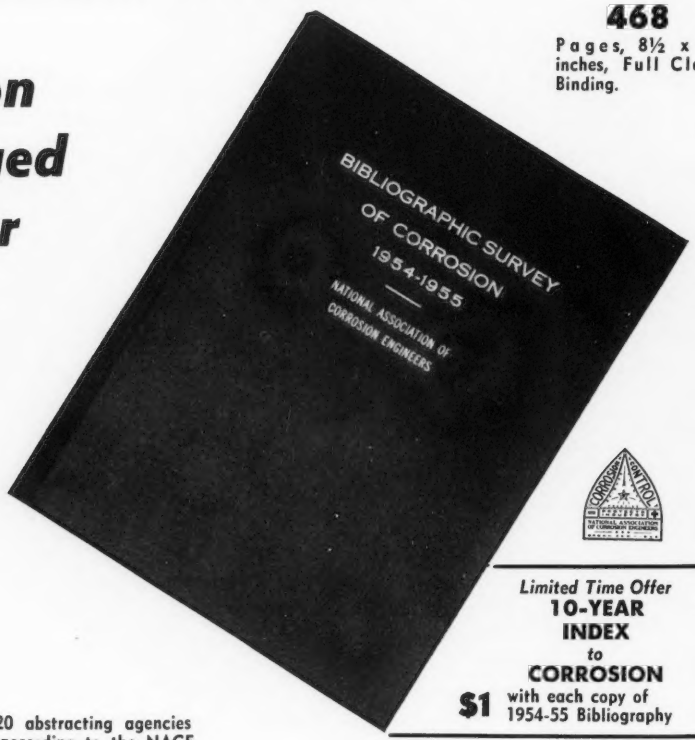


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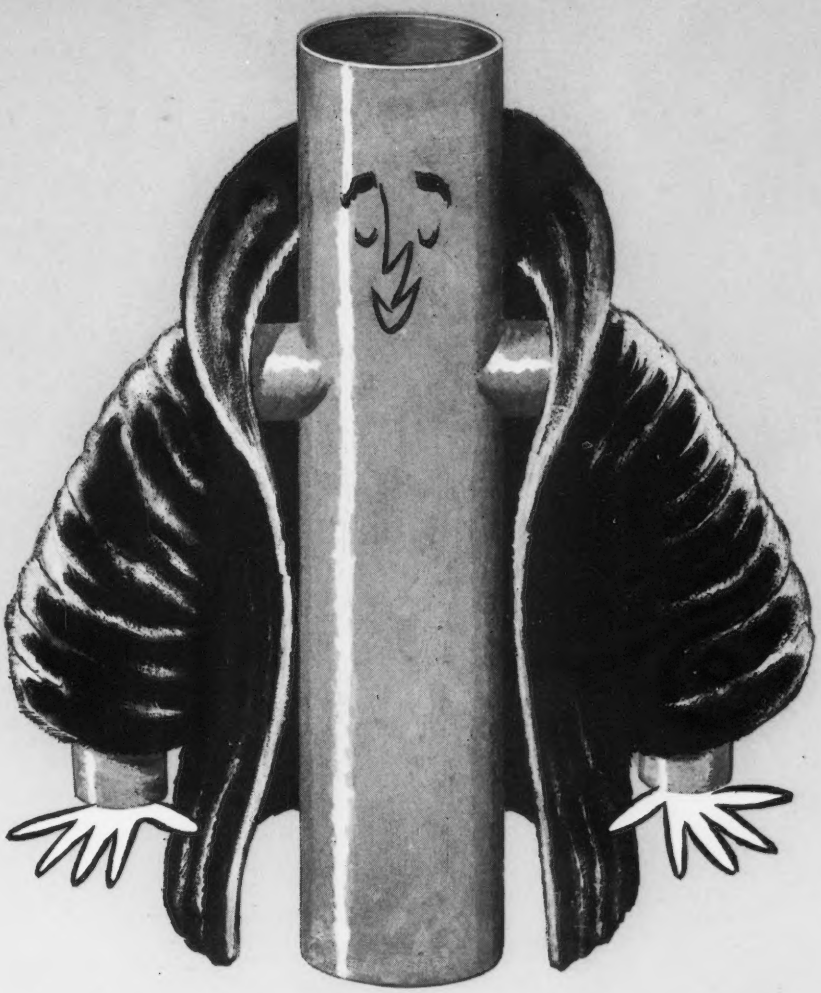

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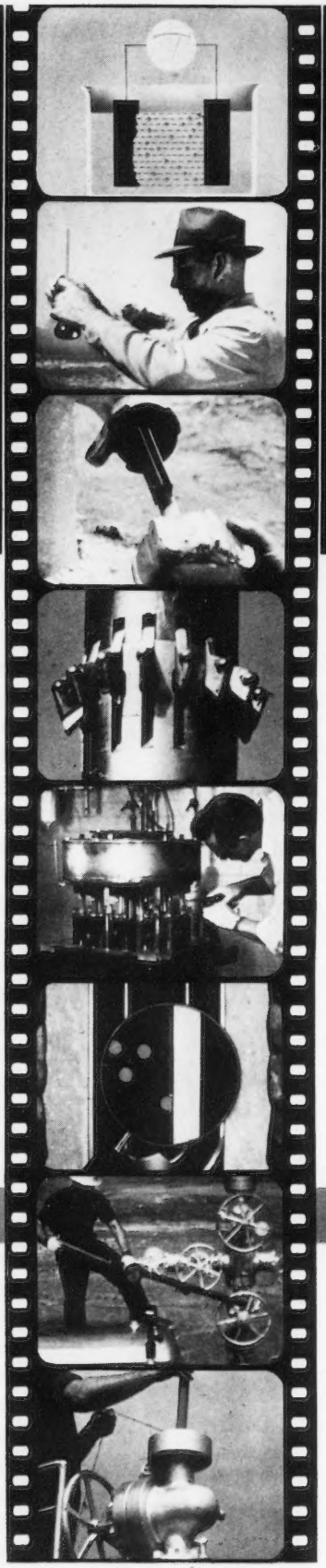


# ANOTHER HELPFUL SERVICE from TRETOLITE

An instructive film, "OIL and GAS WELL CORROSION," is made available to oil companies, schools, and other organizations at no charge. The film was prepared by the Petroleum Extension Division of the University of Texas. It is a 28-minute, 16mm color film, with sound.

*Shows:*
- **Causes of Corrosion**
- **Test Methods**
- **Corrective Measures**

*. . . and much more*

**TO OBTAIN THIS FILM,** just complete the coupon and mail it to:

**Technical Service Manager**
**Tretolite Company**
**369 Marshall Avenue, Saint Louis 19, Missouri**

This film is also available from:

**Tretolite Company of California**
**5515 Telegraph Road, Los Angeles 22, California**

**A SPANISH LANGUAGE EDITION** can be had by writing to:

**Mr. Mont Land**
**Petrolite Corporation**
**Hotel Avila, Caracas, Venezuela**

*or* **Hotel St. Moritz, Paris 11, Mexico, D. F.**

**TRETOLITE COMPANY**
DIVISIONS OF PETROLITE CORPORATION

*Chemicals and Services for the Petroleum Industry*

DEMULSIFICATION • DESALTING • PARAFFIN REMOVAL • SCALE PREVENTION • CORROSION INHIBITING • WATER DE-OILING • INJECTIVITY STIMULATION

TRETOLITE COMPANY:

We are interested in viewing the film "OIL and GAS WELL CORROSION."

Name:_____

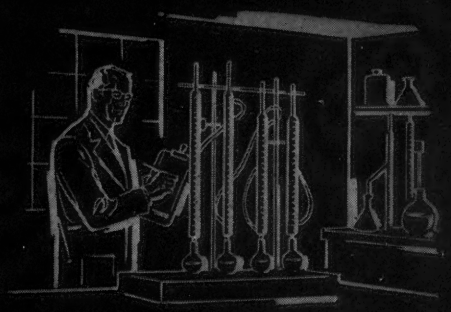
Company or Organization:_____

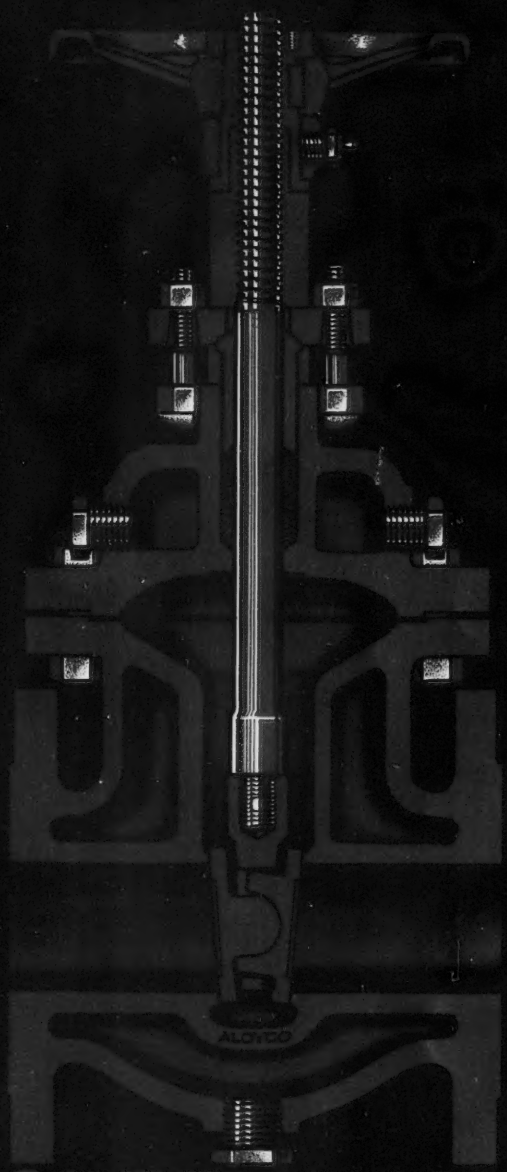
Address:_____

IF POSSIBLE, WE WOULD LIKE TO SHOW THE FILM ON OR ABOUT:

First Choice:_____ Second:_____

KF-58-18






# Thirty years' research devoted exclusively to...

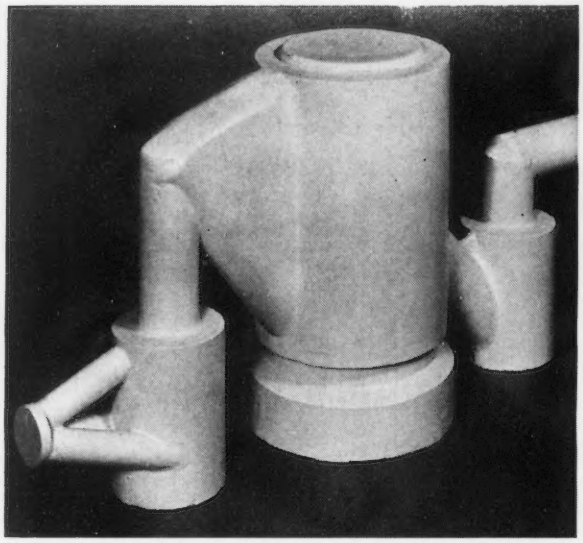
# STAINLESS STEEL VALVES

Aloyco's specialized research . . . in the field and in the lab . . . brings you a wealth of metallurgical information for successfully solving your corrosives-handling problems.

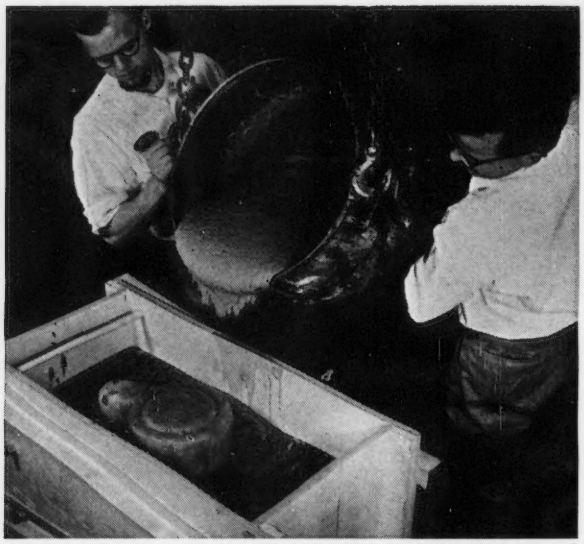
Coupled with continuing research in design, foundry and machining techniques, this Aloyco specialization results in new and better corrosion resistant valves for many specific applications. One example above: Aloyco completely jacketed valves (the first ever to be integrally cast in high alloys) are designed for viscous liquids and other fluids difficult to move at room temperatures.

Isn't your surest source of supply the one company with research, manufacturing and sales all devoted to Stainless Steel Valves exclusively?

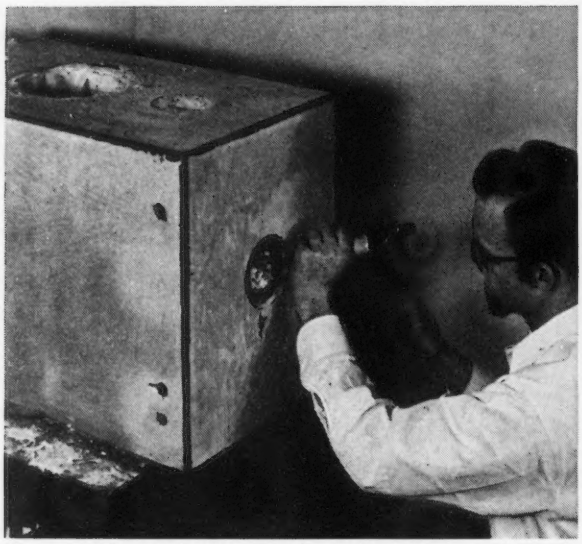
**ALLOY STEEL PRODUCTS COMPANY**
Linden, New Jersey



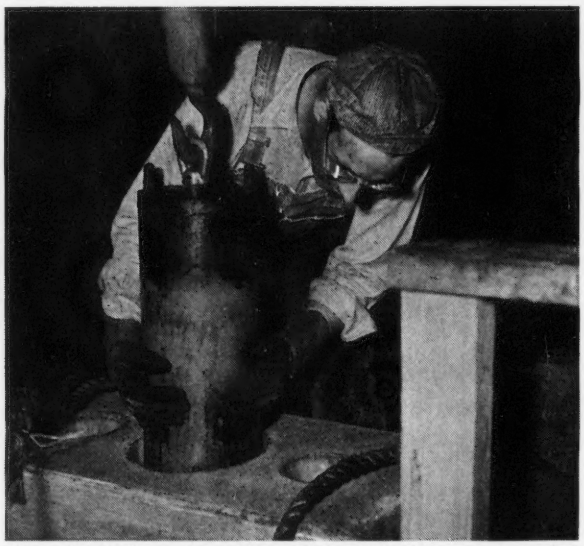
To shape the inside of the bromide-bromine liquor pump block, a form is made of plaster of Paris and Styrofoam®.



Dow Epoxy Resin 331 (casting formulation supplied by Ren Plastics, Inc.) is poured over the form and hardens.



The plaster of Paris and Styrofoam material in the form is broken up and removed.



Main part of bromine pump is installed, ready to operate without wear or corrosion!

# Dow Epoxies help stop corrosion for chemical processors

This corrosion-free pump block adds another to the list of success stories made possible by new, pure Dow Epoxy Resins.

For years the main parts of bromide liquor pumps have been made with machined soapstone. Performance was inconsistent; the slightest crack or seam proved disastrous. But now Dow Epoxies open a new era of efficiency and economy for the chemical processing and corrosion fields. Easily cast to shape without costly machining, the epoxy pump blocks are impervious to the chemicals involved and free from the internal flaws of soapstone.

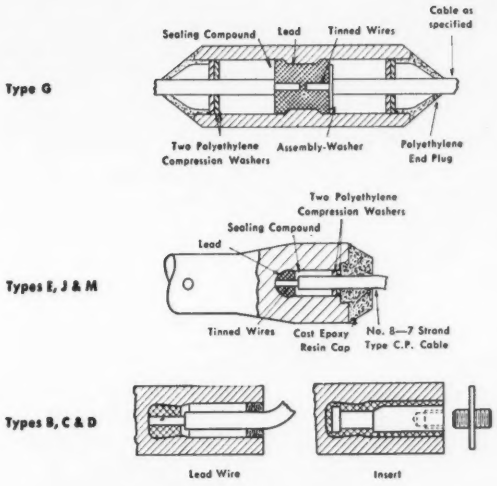
Have you a corrosion problem where Dow Epoxies may help? Write for information and technical help. Dow is a basic producer of the raw materials used in epoxy production. In this way Dow provides raw materials with optimum properties to produce superior resins, to control quality carefully and to provide a narrower range of specifications in the finished resin—so necessary to uniform performance. For complete information and technical data on Dow Solid and Liquid Epoxy Resins, consult your Dow sales office. Or write THE DOW CHEMICAL COMPANY, Midland, Michigan, Coatings Sales Department 2265R.

EPOXY T.M.

YOU CAN DEPEND ON DOW

# DURIRON® IMPRESSED CURRENT ANODES

For more positive cathodic protection of all types of structures used throughout the petroleum industry, insist on DURIRON® ANODES. Duriron performs as well as graphite in all the easy services, and far outperforms graphite when the going gets tough in marshlands, at river crossings, or wherever it is impractical to use backfill. Duriron anodes have proven their superiority for the protection of pipelines, drilling rigs, well casings, storage tanks, and similar structures. For real protection, get Duriron.




**STANDARD ANODE SIZES**

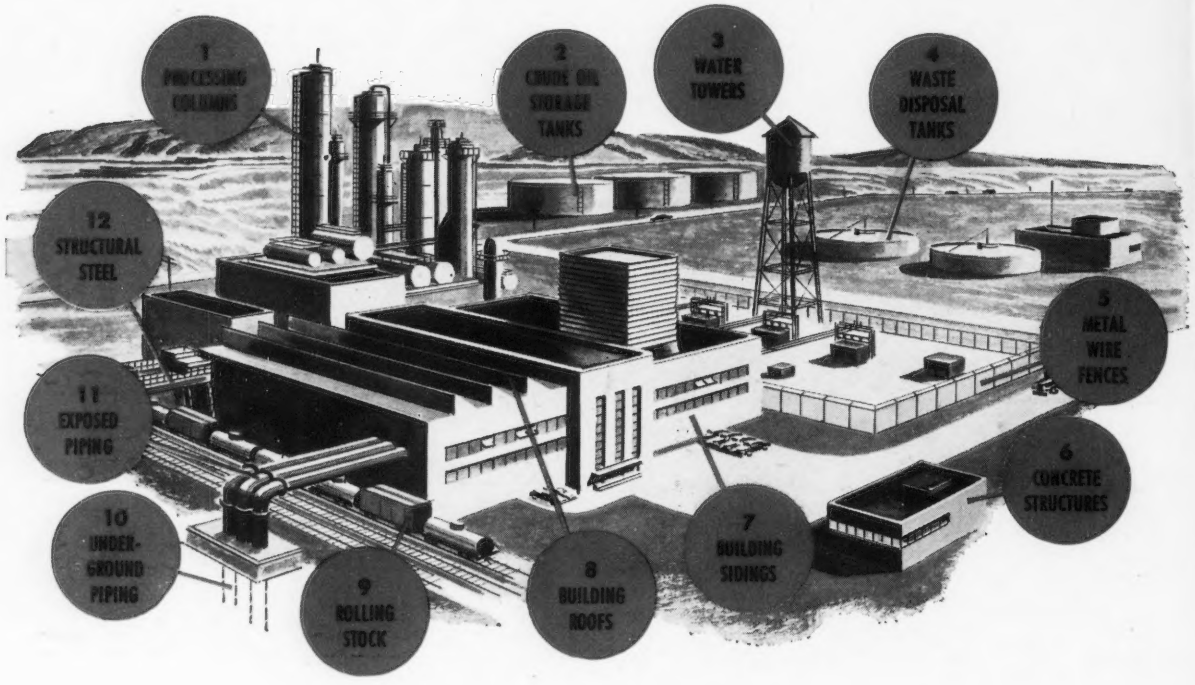
| Type Anode | Size | Area Sq. Ft. | Weight (Lbs.) | General Application |
|---|---|---|---|---|
| B | 1" x 60" | 1.4 | 14 | Fresh Water |
| C* | 1½" x 60" | 2.0 | 25 | Ground Bed |
| D | 2" x 60" | 2.6 | 46 | Ground Bed |
| E | 3" x 60" | 4.0 | 115 | Salt Water |
| G | 2" x 9" | 0.4 | 5 | Ducts |
| J | 3" x 36" | 2.5 | 80 | Salt Water |
| M | 2" x 60" | 2.8 | 57 | Salt Water |

*Applicable also in fresh water service. Should not be used in ground beds without backfill.

**THE DURIRON COMPANY, INC. / DAYTON, OHIO**

DURCO
CORROSION RESISTING ALLOYS & EQUIPMENT

# Solve Your Plant's Toughest Corrosion Problems with these PITT CHEM Coatings




**1. Processing Columns**—For corrosion control alone, use *Insul-Mastic 4010* gilsonite-asphalt vaporseal. For insulation and corrosion protection, use *Insul-Mastic 553* Type D with incorporated cork granules.

**2. Crude Oil Storage Tanks**—For bottom and top of interiors, use patented PITT CHEM *Tarset* coal tar-epoxy resin coating. For exterior use *Insul-Mastic 4010, 553* or PITT CHEM *101* coal tar coating.

**3. Water Towers**—For interior, use tasteless, odorless PITT CHEM *104* coal tar coating. For exterior, use *Insul-Mastic 4010.*

**4. Waste Disposal Tanks**—Use acid and alkali-resisting *Tarset* or tough, heavy-bodied PITT CHEM *101.*

**5. Metal Wire Fences**—Apply weather-resisting PITT CHEM *102* coal tar coating with roller or brush.

**6. Concrete Structures**—Use *Insul-Mastic 4010* vaporseal or *Mica-Mastic 5402,* a synthetic resin coating containing white mica, specifically compounded for waterproofing and decorating masonry.

**7. Building Sidings**—Weatherproof with *Insul-Mastic 4010* and finish with *Insul-Mastic Color Coat.* Available in eight shades, *Color Coat* is specifically designed for use over PITT CHEM coal tar and *Insul-Mastic* coatings.

**8. Building Roofs**—Use *Insul-Mastic* roofing coatings outside. For condensation control and insulation on underside, use *Insul-Mastic 553.*

**9. Rolling Stock**—Apply *Insul-Mastic Dednox* coatings for protection of frames, box car ends and roofs of railroad cars.

**10. Underground Piping**—Use PITT CHEM *Tarset* or PITT CHEM *101* heavy duty coal tar coating.

**11. Exposed Piping**—Protect with *Tarset or Insul-Mastic 4010* and code with *Insul-Mastic Color Coat.*

**12. Structural Steel**—Apply economical, weather-sealing *Insul-Mastic 4010.*

THERE'S hardly a corrosion problem around your plant that can't be controlled with a PITT CHEM coal tar or INSUL-MASTIC gilsonite-asphalt coating. From ordinary weatherproofing to stopping tough chemical and underground corrosion, there's a PITT CHEM coating to do the job efficiently and economically.

**Pitt Chem Industrial Coatings are available through leading Industrial Distributors. See the "Yellow Pages" of your telephone directory.**

PROTECTIVE COATINGS DIVISION
**PITTSBURGH COKE & CHEMICAL CO.**
Grant Building • Pittsburgh 19, Pa.

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